ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY

COLLEGE OF ARCHITECTURE AND CIVIL ENGINEERING

EFFECT OF JUTE FIBER ON THE STRENGTH OF C-30 CONCRETE

A Thesis Submitted to the Graduate School of Addis Ababa Science and Technology University in Partial Fulfilment of the Requirements for the Degree of Masters of Science

In

Civil Engineering

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APPROVAL PAGE

This Msc thesis entitled with "***Effect of jute fiber on the strength of C-30 concrete***" has been approved by the following examiners in partial fulfillment of the requirement for the degree of Master of Science in **Structural Engineering**.

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CERTIFICATION

I, the undersigned, certify that I read and hear by recommend for acceptance by Addis Ababa science and Technology University a dissertation entitled “Effect of jute fibre on the strength of C30 concrete” in partial fulfilment of the requirement for the degree of Master of Science in Structural Engineering specialized in Structural Engineering.

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I, **Abeba Asrat** declare that this thesis is my own original work that has not been presented and will not be presented by me to any other University for similar or any other degree award.

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ABBREVIATIONS

ACI =American concrete institute

AR-GFRC = Alkali resistant glass fiber reinforced concrete

AR-Glass fibers =Alkali resistant glass fibers

CBC = Carpet Backing Cloth

FRC = Fiber reinforced concrete

GFRC = Glass fiber reinforced concrete

JFRC = Jute fiber reinforced concrete

JSCE = Japanese Society of Civil Engineering

$L_5V_{0.5}$=Concrete mix with 5mm length and 0.5% volume fiber

L_5V_1=Concrete mix with 5mm length and 1% volume fiber

L_5V_2=Concrete mix with 5mm length and 2% volume fiber

$V_{0.5}$ L_5=Concrete mix with 0.5% volume and 5mm length fiber

$V_{0.5}$ L_{15}=Concrete mix with 0.5% volume and 15mm length fiber

$V_{0.5}$ L_{25}=Concrete mix with 0.5% volume and 25mm length fiber

MR =Moisture regain

N/A = Property not readily available or not applicable

PCA = Portland Cement Association

PNF = Processed natural fiber

SFRC =Steel fiber reinforced concrete

SG =Specific gravity (average fiber density)

SIFCON = Slurry infiltrated fiber concrete

SSD = Saturated surface dry

UNF = Unprocessed natural fiber

Abstract

Concrete is weak in tension and has brittle character which has no significant post-cracking ductility. The use of continuous reinforcement in concrete or ordinary reinforced concrete increase strength and ductility, thus improve long term serviceability of concrete structure. But ordinary reinforced concrete is rather becoming expensive in production costs, transportation of pre-cast members, maintenance costs and the supply of much amount of steel. And there has been shortage of cheap but durable building materials for the construction of low cost, energy consumption and environmental friendly housing. The use of jute fiber reinforced cement composite may offer a possible solution in this respect which has not been used in our country until now. This study was initiated to explore the feasibility of utilizing this fiber for producing fibrous composite for improving the mechanical properties of concrete especially in terms of using readily available local materials achieving high strength C30 grade concrete. To accomplish the objective, experiments were conducted on jute fiber reinforced concrete. The principal variable of the testing program is the amount (percent by volume) and the length of jute fiber. Specimens were prepared and tested under standard specification for slump, compressive, flexural and tensile strength. The experimental result indicated improvement of the mechanical properties with the inclusion of jute fiber. The addition of fiber shows more improvement in flexural strength than other properties such as compressive strength, tensile strength and ductility behavior. Among the percentages and length studied, the 0.5 % (by cement weight) with 5mm length exhibited the most efficient proportion resulting in improved mechanical property (more than two folds strength gain from other fiber volume percentage and length). But further increment of fiber length and volume causes relative strength loss caused by balling in the concrete. Thus the jute fiber reinforced concrete is reliable material to be used in practice for the production of structural elements to be used in rural construction where these fibers are abundant.

Key words: Concrete, reinforced concrete, jute fiber

CHAPTER ONE

INTRODUCTION

1.1. General

The construction industry is developing with the invention of different materials to make tasks efficient; reduce time and cost; improve durability, quality and performance of structures during their life time. This leads to the development of special concrete such as polymer concrete for high durability, fiber reinforced concrete for preventing cracks in concrete, high and ultra-strength concrete for applications in tall buildings and bridges, light weight concrete for reducing foundation loads and high performance concrete for special performance requirements. Since Ethiopia's share in the annual fiber reinforced concrete production is null, this thesis concerns about developing fiber reinforced concrete.

Cement concrete is useful in a variety of designs as it can be cast to any desired shape and possess high compressive strength and stiffness, low thermal and electrical conductivity. However its low tensile strength, limited capacity and little resistance to cracking limited its application. Internal micro cracks are inherently present in the concrete. It has poor tensile strength due to the propagation of such micro cracks leading to brittle fracture of the concrete and brittle materials do not have post cracking ductility that cement concrete has negligible elongation at break. Therefore it is normally reinforced with steel reinforced bars or restraining technique is applied. But the conventional steel reinforcement makes the reinforced cement concrete structure heavy and due to water or moisture diffusion through micro cracks developed, steel starts corroding leading to failure of concrete. Moreover, although they provide strength to the concrete members, they however do not increase the inherent tensile strength concrete itself. They also falls short of desirable properties like toughness, ductility, controlling cracking and energy absorption property because the reinforcement component in reinforced cement concrete is present in certain pockets of the cross section of the structural member. Therefore it is essential to distribute the reinforcement uniformly throughout the cross section by adding short fibers of small diameter that are metallic or nonmetallic to the constituents of the concrete mix. This new material with improved mechanical properties is called **"Fiber Reinforced Concrete".**

The term fiber reinforced concrete is defined by ACI committee 544 as a concrete made of hydraulic cements containing fine or fine and coarse aggregate and discontinuous discrete fibers. Fiber reinforced concrete has two phases in which concrete represents the matrix phase and fiber constitutes the inclusion phase. The fiber increases the energy absorption capacity and toughness of the material and increases tensile and flexural strengths of concrete. Generally it improves mechanical properties of the concrete. Fiber reinforced concrete composites can be used in various fields of application like permanent frame works, paver blocks, wall panels, pipes, long span roofing elements and strengthening of existing structures and structural building members. [13]

Furthermore, composites with light weight high strength to weight ratio and stiffness properties have come along the way in replacing the conventional materials like metals, woods etc. The replacement of steel with composites can save up to 60 to 80 percentage of component weight and 20 to 50 weight percentages with aluminum components, the polymer based composite materials use is increasing because of their light weight, good mechanical and tri biological response. However composites encounter problems such as fracture, matrix cracking of this fiber fracture and matrix cracking plays an important role in laminating under tensile load. [3]

Moreover, conventional concrete is designed on the basis of compressive strength which does not meet many functional requirements such as impermeability, resistance to environment and frost, thermal cracking adequately. As a result innovations of supplementary materials and composites have been developed for enhancing mechanical properties and durability. [17]

Fiber is a small piece of reinforcing material which can be circular or flat. It is often described by a convenient parameter called aspect ratio which is the ratio of its length to its diameter. Our ancestors have been adding straw fibers to a mud in wall construction to create a composite with a better performance. [13]

There are different types of fibers available for commercial and experimental use. Fibers are divided according to the origin of the fiber material as artificial and natural fiber. Artificial fiber is disadvantageous due to its high cost, health and environmental hazards. Natural fibers are which are produced from naturally available resources like coconut tree, banana tree, cotton, jute etc. Natural fiber offers the opportunity as a convenient reinforcing agent in concrete due to its low density and light tensile property. Its advantage over the conventional reinforcing fibers like glass, synthetic, carbon, steel etc. are its abundant availability, low cost, less abrasiveness, ability to absorb mechanical impact, easy to handle and process and environmental friendliness. The potential application of natural fiber reinforced concrete is limited to those areas where energy is absorbed or the area prone to damage. Thus it is suitable for shatter and earthquake resistant construction, foundation floor for machinery in factories, fabrication of light weight cement based roofing and ceiling boards, wall plaster and construction materials for low cost housing. The characteristics of fiber, nature of cement based matrix, the way of mixing, and casting and curing of the composite are factors that influence the mechanical properties of fiber reinforced concrete reinforced with natural fiber. [3]

Researchers have conducted studies on the effect of natural fibers on the mechanical and physical behavior of concrete to investigate the extent of improvement. The composite achieved considerable strength and toughness of the composite.

Jute is one of the natural fibers to reinforce the concrete. It is an important bast fiber with a number of advantages. It has high specific properties, low density, less abrasive behavior to the processing equipment, good dimensional stability and harmlessness, abundant available, easy to transport, has superior moisture retention capacity. Being made of cellulose on combustion, jute does not generate toxic gases. Due to its low density combined with relatively stiff and strong behavior, the specific properties of jute fiber can be compared to those of glass and some other fibers. Its production needs much less energy. It can be substitute of asbestos cement composite, which is a serious hazard to human and animal health and is prohibited in industrial countries. [13]

Thus the objective of the present investigation is to study the mechanical properties of jute fiber reinforced concrete focusing on its ductility behavior.

1.2. Objective of the thesis

The general objective of this study is to characterize the physical and mechanical properties in the hardened state and list the benefits obtained by the concept of jute fiber reinforced concrete over conventional reinforced concrete by studying the effect of fiber on the compressive, flexural and tensile strength of jute fiber reinforced concrete.

And also the sustainability of short jute fiber as a reinforcing agent in cement concrete is proved using locally available materials here in Ethiopia.

1.3. Statement of the problem

Concrete's low tensile strength, limited capacity and little resistance to cracking limited its application. Internal micro cracks are inherently present in the concrete. It has poor tensile strength due to the propagation of such micro cracks leading to brittle fracture of the concrete and brittle materials do not have post cracking ductility that cement concrete has negligible elongation at break. Therefore it is normally reinforced with steel reinforced bars or restraining technique is applied. But this reinforcement makes the structure heavy and leads to structure failure due to corrosion of steel because of water or moisture diffusion through micro cracks. And also it has difficulties in getting the desirable properties like toughness, ductility, controlling cracking and energy absorption because the reinforcement is found in some parts of the cross section of the structural member. Ordinary reinforced concrete is also expensive in production costs, transportation of precast members, maintenance costs and the supply of much amount of steel.

Conventional concrete is designed on the basis of compressive strength in which it doesn't concern the functional requirements such as impermeability, resistance to environment and frost, thermal cracking adequately.

There is lack of cheap but durable building materials for the construction of low cost, low energy consumption and environmental friendly housing.

1.4. Research Significance

This study is expected to contribute to the development of new concrete application area in the Ethiopian construction industry by characterizing the mechanical properties of jute fiber reinforced concrete.

Jute fiber reinforced concrete will contribute in the development of the modern concrete technology which can be applied in permanent frame works, paver blocks, wall panels, pipes, long span roofing elements, strengthening of existing structures and structural building members [3].

This study will also encourage jute fiber factories to use jute fiber as a construction material. Furthermore it is hoped that this report would be helpful towards commercial application of this technology.

1.5. Structure of the research

The thesis contains four chapters that the first chapter describes a general introduction with objective, research significance and methodology is described in the first chapter.

Chapter two explains about fiber reinforced concrete, fiber types with their properties and current applications of the reinforced concrete. Moreover, the factors affecting these properties and the measurement of the properties of the fiber reinforced concrete are discussed. This chapter briefly discusses about natural reinforced concrete focusing on jute fiber reinforced concrete. The properties of jute fiber and the inclusion effect on the hardened and fresh concrete is overviewed. The summary of mix design recommendations, mixing, placing, compaction and finishing techniques and practical applications of jute fiber reinforced concrete is provided.

Chapter three deal with the experimental study of jute fiber reinforced concrete. Properties of materials, mix proportions, mixing, casting, and curing procedures are explained in detail. Procedures applied to perform related tests are explained.

Results and discussions of the experimental results are covered in chapter four.

Chapter five gives the general and specific conclusions with recommendations for further research work followed by list of references.

The annex gives the results of the individual tests, other relevant data and representative photos taken during the research work. Graphs are used to show trends and to describe relationships. Statically analysis of the data collected is presented with tables. Other important data are recorded in the annexes for cross-referencing.

CHAPTER TWO

LITERATURE REVIEW

2.1. Fiber reinforced concrete

Construction industries are facing problems of cracking and tensile strength problems in concrete for that we have to add something in concrete to improve the tensile property. Adding a small amount of fibers is a good solution for this. Different types of fiber namely steel, carbon, asbestos, jute, glass, polythene, nylon, polypropylene, fly ash, polymer, epoxy, super plasticizer, etc. [14]

Fiber reinforced concrete can be defined as a composite material consisting of mixtures of cement mortar or concrete and discontinuous discrete, uniformly, dispersed fibers which increases its structural integrity. The fiber improves the tensile strength, flexural strength, resistant to crack, toughness, shearing strength, shock resistance, etc. It also helps make the concrete stronger and more resistant to temperature extremes and improve the concrete water resistance. The reinforcement is in the form of short fibers of small diameter distributed throughout the matrix. The length and diameter of the fibers used do not exceed 76mm and 1mm respectively. Steel fiber is the most commonly used for most structural and nonstructural purposes.

The fiber materials, geometries, distribution, orientations and densities are the factors for the character of fiber reinforced concrete. The fiber must have the following properties to be effective in the concrete matrix.

a) It’s tensile strength must be significantly higher than that of concrete
b) It’s bond strength with concrete matrix preferably be of same order or as higher than the tensile strength of matrix
c) It’s elastic modulus in tension to be significantly higher than that of the concrete and
d) The poison’s ratio and the coefficient of thermal expansion should preferably be of same order as that of the matrix.

The fibers in the concrete changes post-elastic property that range from subtle to substantial depending on number of factors, including matrix strength, fiber types, fiber modulus, and fiber aspect ratio, fiber strength, fiber surface bonding characteristics, fiber content, fiber orientation and aggregate size effects. The fiber does not increase the ultimate tensile strength appreciably but increase the tensile strains at rupture do. The matrix first-crack strength is not increased but the most significant enhancement is the post-cracking composite response. [13]

Fiber reinforced concrete is also much tougher and more resistant to impact than plain concrete. Typical load deflection curves for plain concrete and fiber reinforced concrete are shown below.

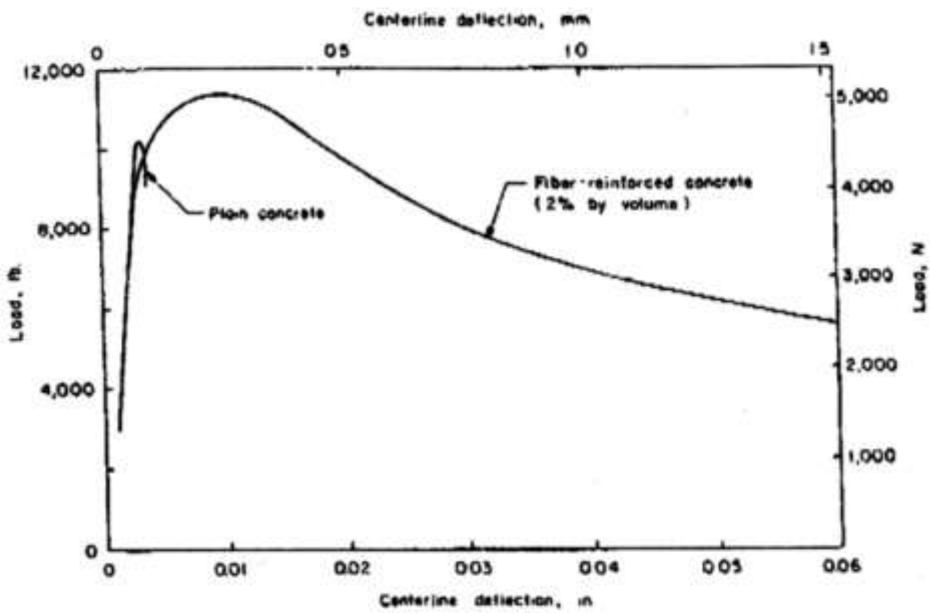

Fig 2. 1. Typical load deflection curve for plain and fiber reinforced concrete [8]

Plain concrete fails suddenly once the deflection corresponding to the ultimate flexural strength is exceeded; on the other hand, fiber reinforced concrete continues to sustain considerable loads even at the deflection of the plain concrete. Failure takes place primarily due to fiber pullout or deboning in fiber reinforced concrete and unlike plain concrete a fiber reinforced concrete does not break immediately after the initiation of the first crack. This has the effect of increasing the work of fracture, which is referred to us toughness and represented by the area under the load deflection curve. In fiber reinforced concrete, crack density is increased, but the crack size is decreased.

2.2. Historical background of fiber reinforced concrete

Man has known that two or more materials could be combined to form a new material with enhanced material properties for a long time which is called composite material. Composite material may be defined as the combination of two or more materials to form another useful material. A very common example would be steel reinforced concrete that is used to construct buildings and road ways. [7]

Another composite material is fiber which has been used to reinforce the brittle materials since ancient times. Straws were used to reinforce sun baked bricks; horse hair was used to reinforce plaster and more recently asbestos fibers are being used to reinforce Portland cement. The low tensile strength and brittle character of concrete have been by passed by the reinforcing rods in tensile zone of the concrete since the middle of the nineteenth century. The Portland cement association (PCA) investigated fiber reinforcement in the late 1950. Experiments using glass fibers have been conducted in the United States since the early 1950 as well as the United Kingdom and Russia.

In the 1950s, composite material concept is thought and FRC was one of the topics. By the 1960s steel, glass and synthetic fiber such as polypropylene fibers were used in the concrete.

Natural fibers have been used for apparel and home fashion for thousands of years. Use of glass fiber was first attempted in the former USSR in the late 1950s. It was seen that ordinary glass fibers are attacked and eventually destroyed by the alkali in the cement paste and considerable development work was done producing a form of alkali-resistant glass fibers containing zirconia.

Attempts of using synthetic fibers (nylon, polypropylene) were made and researchers concluded that both synthetic and natural fibers can successfully reinforce concrete. [13]

Use of asbestos fibers in cement paste matrix began with the invention of the Hatschek process in 1898. It is widely used throughout the world today. However due to health hazards associated with asbestos fibers, alternate fiber types were introduced throughout the 1960s and 1970s.

In modern times, a wide range of engineering materials incorporate fibers to enhance composite properties like tensile strength, compressive strength, elastic modulus, crack resistance and control, durability, fatigue life, resistant to impact and abrasion, shrinkage, expansion, thermal characteristics and fire resistance.

During the early 1960s in the United States, the first major investigation was made to evaluate the potential of steel fibers as reinforcement for concrete. Since then a research development, experimentation and industrial application of steel fiber reinforced concrete has occurred.

The ACI committee 544 published a state of the art report in 1973. Rilem's Committee on FRC cement composites has also published a report. A recommended practice and a quality control manual for manufacture of glass fiber reinforced concrete panels and products have been published by the precast/pre stressed concrete institute. [8]

2.3. Types of fiber reinforced concrete

Fiber is a small piece of reinforcing material possessing certain characteristic properties. It can be circular or flat and often described by a parameter called "aspect ratio". It is the ratio of its length to its diameter which ranges from 30 to 150. Generally there are two different types of fibers i.e. natural fibers and artificial polymer based fibers. These fibers reinforcing the concrete are discussed in the following sections with their physical properties and applications.

2.3.1. Steel fiber reinforced concrete

Steel fiber reinforced concrete (SFRC) is concrete made of hydraulic cements containing fine or fine and coarse aggregate and discontinuous discrete fibers. Fiber pull out cement matrix lead to failure of the concrete. The properties of SFRC are affected by its composite nature. It is also affected by the properties of fibers (volume percentage, strength, elastic modulus and a fiber bonding parameter of the fibers), the concrete properties (strength, volume percentage and elastic modulus), and the properties of the interface between the fiber and the matrix. The energy to extend a crack and de bond the fiber in the matrix relates to the properties of the composite.

Steel fiber reinforced concrete is advantageous than conventional reinforced concrete in use in construction. It can be used for tunnel lining rock slop stabilization and as lagging for the support of excavation. Labor is not needed for placing mesh or reinforcing bars.

Steel fiber is composed of carbon steel or stainless steel. It must have an aspect ratio from 20 to 100. The length range from 0.25 to 3 in (6.4 to 76 mm).Cold drawn wire, cut sheet, melt extracted and other fibers are classified as steel fiber types based on product used by ASTM A820. The Japanese society of civil engineers (JSCE) has classified steel fiber based on the shape of the cross section. Steel fiber is produced by cutting or chopping wire, or by shearing sheet of flattening wire. Crimped and deformed steel fibers have been produced. The mechanical bonding is increased with deformation made by bending or flattening. Steel fibers are also produced by the melt-extraction process.

Steel fibers have a relatively high strength and modulus of elasticity. Alkaline environment of cementitious matrix protect the steel fiber from corrosion and mechanical anchorage or surface roughness enhance their bond to the matrix. The mechanical properties of steel fibers are not affected by long term loading. The ductility of the steel fiber reinforced concrete is improved depending on the type and volume percentage of fibers present. Steel fibers improve the ductility of concrete under all modes of loading. It improves compression, tension, shear, torsion and flexure in varying amount.

There is a significant increase in flexural fatigue strength with increasing percentage of steel fiber. Steel wire reinforcement at volumes less than 1 percent have no significant effect on the creep and shrinkage behavior of Portland cement mortar and concrete. The modulus of elasticity and poison’s ratio of SFRC is the same as those of similar non-fibrous concrete or mortar, when the volume percentage of fibers is less than 2 percent. A steel fiber reinforced mortar pot withstands multiple hammer blows before a hole is punched at the point of impact. Steel fiber has no effect on abrasion resistance of concrete by particulate debris carried in slowly flowing water. It also had higher skid and rolling resistance than plain concrete under dry, wet and frozen surface conditions.

SFRC must be air entrained for having freezing and thawing resistance. The corrosion should be only up to the surface skin of the concrete. The corrosion does not propagate after the surface fiber corrodes. Cracking occurs because concrete is almost always restrained. The addition of steel fibers may not reduce the total amount of restrained shrinkage and can increase the number of cracks and thus reduce the average crack widths.

The present applications of SFRC are on cast-in place SFRC, precast SFRC, on shotcrete, SIFCON (slurry infiltrated fiber concrete) and refractories.

2.3.2. Glass fiber reinforced concrete

The very high alkalinity of the cement based matrix of E-glass, A-glass makes to lose strength. A-glass and E-glass composites cannot be used for long term use.AR glass fiber is a new alkali resistant fiber which provide improved long-term durability. This system was named alkali-resistant glass fiber reinforced concrete (AR-GFRC).GFRC materials can be fabricated by “spray up” and “the premix” process. The premix process consists of mixing cement, sand, chopped glass fiber, water, and admixtures together into a mortar using standard mixers and casting with vibration, press-molding, extruding, or slip-forming the mortar into a product.

The mechanical properties of GFRC are affected by extended exposure to natural weather environments. And also exposure of GFRC to normal natural weathering cycles (moisture and temperature cycles) will result in cyclical volumetric dimension changes. The cement matrix can be effectively preserved against significant freeze-thaw deterioration in AR-glass fibers comparing with unreinforced matrix.

GFRC has been largely applied for the manufacture of exterior building facade panels and for surface bonding. Other applications are such as electrical utility products like trench systems and distribution boxes. A growing application of GFRC is building restoration, replacing existing walls and ornate the facades capitalizing on the light weight and shape versatility of the composite.

2.3.3. Synthetic fiber reinforced concrete

Synthetic fibers are manmade fibers resulting from research and development in the petrochemical and textile industries. Fibers derived from organic polymers are utilized in SNFRC which are available in a variety of formulations. Acrylic, Aramid, Carbon, and Nylon, polyester, polyethylene and polypropylene are commercially available synthetic fibers. Low range of addition approximately 0.1 percent based on volume of concrete are added to concrete in current commercial and industrial bulk concrete applications.

Synthetic fiber reinforced concrete is used worldwide in applications of cast-in-place concrete (such as slabs-on-grade, pavements and tunnel linings) and factory manufactured products (such as cladding panels, sidings, shingles and vaults). Uses include precast products, shotcrete, and cast-in-place elements.

The other type of fiber reinforced concrete called natural fiber reinforced concrete is described briefly in the last section.

2.4. Properties of fiber reinforced concrete

2.4.1. Mechanical properties of fiber reinforced concrete

The mechanical properties of concrete depend on the type and percentage of fiber. Crimped-end fibers can achieve the same properties as straight fibers using 40 percent less fibers. The same equipment and procedure as conventional concrete can be used.

The fiber effect on the improvement of compressive strength is small (0 to 15%). But the failure mode is changed by the addition of fiber.

Slight increment of modulus of elasticity is shown by increasing the fiber content. When 1 percent fiber is increased in content by volume, there is 3 percent increment in the modulus of elasticity.

The most significant contribution of fiber reinforcement to concrete is not to strength but to flexural strength of the material (total energy absorbed in breaking a specimen in flexure). The flexural strength is increased by 2.5 times using 4 percent fibers.

Toughness is about 10 to 40 times increased from the plain concrete.

The split tensile strength of mortar is increased 2.5 times that of unreinforced one by the inclusion of 3 percent fiber by volume.

The presence of fibers increases fatigue strength of about 90 percent and 70 percent of the static strength at 2x10^6 cycles for non- reverse and full reversal of loading respectively.

The impact strength is increased 5 to 10 times that of plain concrete depending on the volume of fiber used.

2.4.2. Structural behavior of fiber reinforced concrete

The addition of fiber changes the failure not to be sudden compared to that of the plain concrete beams. It increases stiffness, torsion strength, ductility, rational capacity and the number of cracks with less crack width.

The shear capacity of reinforced concrete beams is increased up to 100 percent by the addition of fibers.

The ductility of axially loaded specimen slightly increases the fiber content. The sudden type of failure is reduced for columns. The ductility of high strength concrete is increased with the addition of fibers and fiber reinforcement effectively controls cracking and deflection and improves the strength.

2.5. Factors affecting properties of fiber reinforced concrete

The reinforced concrete properties would obviously depend up on the efficient transfer of stress between matrix and the fibers. The factors are briefly discussed below

2.5.1. Relative fiber matrix stiffness

The modulus of elasticity of matrix must be much lower than that of fiber for efficient stress transfer. Low modulus of fiber such as nylons and polypropylene are, therefore, unlikely to give strength improvement, but the help in the absorption of large energy and therefore, impart greater degree of toughness and resistance to impart. High modulus fibers such as steel, glass and carbon impart strength and stiffness to the composite. Interfacial bond between the matrix and the fiber also determine the effectiveness of stress transfer, from the matrix to the fiber. A good bond is essential for improving tensile strength of the composite.

2.5.2. Volume of fibers

The strength of the composite largely depends on the quantity of fibers used in it. The increase in the volume of fibers, increase approximately linearly, the tensile strength and toughness of the composite. Use of higher percentage of fiber is likely to cause segregation and harshness of concrete and mortar.

2.5.3. Aspect ratio of the fiber

Another important factor which influences the properties and behavior of the composite is the aspect ratio of the fiber. It has been reported that up to aspect ratio of 75, increase on the aspect ratio increases the ultimate concrete linearly. Beyond 75, relative strength and toughness is reduced. The table below shows the effect of aspect ratio on strength and toughness.

Table 2. 1. Aspect ratio of the fiber

Type of concrete	Aspect ratio	Relative strength	Relative toughness
Plain concrete	0	1	1
With randomly dispersed fibers	25	1.5	2
	50	1.6	8
	75	1.7	10.5
	100	1.5	8.5

2.5.4. Orientation of fibers

One of the differences between conventional reinforcement and fiber reinforcement is that in conventional reinforcement, bars are oriented in the direction desired while fibers are randomly oriented. To see the effect of randomness, mortar specimens reinforced with 0.5% volume of fibers were tested. In one set specimens, fibers were aligned in the direction of the load, and in the third randomly distributed. It was observed that the fibers aligned parallel to the applied load offered more tensile strength and toughness than randomly distributed or perpendicular fibers.

2.5.5. Workability and compaction of concrete

Incorporation of fiber decreases the workability considerably. This situation adversely affects the consolidation of fresh mix. Even prolonged external vibration fails to compact the concrete. The fiber volume at which this situation is reached depends on the length and diameter of the fiber. Another consequence of poor workability is non-uniform distribution of the fibers. Generally, the workability and compaction standard of the mix is improved through increased water/cement ratio or by the use of some kind of water reducing admixtures.

2.5.6. Size of coarse aggregate

Maximum size of coarse aggregate should be restricted to 10mm, to avoid appreciable reduction in strength of the composite. Fibers also in effect, act as aggregate. Although they have a simple geometry, their influence on the properties of fresh concrete is complex. The inter-particle friction between fibers and between fibers and aggregates controls the orientation and distribution of the fibers and consequently the properties of the composite. Friction reducing admixtures and admixtures that improve the cohesiveness of the mix can significantly improve the mix.

2.5.7. Mixing

Mixing of fiber reinforced concrete needs careful conditions to avoid balling of fibers, segregation and in general the difficulty of mixing the materials uniformly. Increase in the aspect ratio, volume percentage and size and quantity of coarse aggregate intensify the difficulties and balling tendency. Steel fiber content in excess of 2% by volume and aspect ratio of more than 100 are difficult to mix. It is important that the fibers are dispersed uniformly throughout the mix; this can be done by the addition of the fibers before the water is added. When mixing in a laboratory mixer, introducing the fibers through a wire mesh basket will help even distribution of fibers. For field use, other suitable methods must be adopted [15].

2.6. Application of fiber reinforced concrete

The applications of fibers in concrete industries depend on the designer and builder in taking advantage of the static and dynamic characteristics of this new material. The main area of FRC applications are the following

Runway, aircraft parking and pavements

For the same wheel load FRC slabs could be about one half the thickness of plain concrete slab. Compared to a 375mm thickness of conventionally reinforced concrete slab, a 150mm thick crimped-end FRC slab was used to overlay an existing asphaltic-paved aircraft parking area.FRC pavements are now in service in severe and mild environment.

Tunnel lining and slope stabilization

Steel fiber reinforced shotcrete are being used to line underground openings and rock slope stabilization. It eliminates the need for mesh reinforcement and scaffolding.

Blast resistant structures

When plain concrete slabs are reinforced conventionally, tests showed that there is no reduction of fragments under blast and shock waves. Similarly reinforced slabs of fibrous concrete however showed 20 percent reduction in velocities, and over 80 percent in fragmentations.

Thin shell, walls, pipes and manholes

Fibrous composites permit the use of thinner flat and curved structural elements. Steel fibrous shotcrete is used in the construction of hemispherical domes using the inflated membrane process. Glass fiber reinforced cement or concrete made by spray-up process, have been used to construct wall panels. Steel and glass fiber addition in concrete pipes and manholes improves strength, reduces thickness and diminishes handling damages.

Dams and hydraulic structure

Fiber reinforced concrete is being used for the construction and repair of dams and other hydraulic structures to provide resistance to cavitation and severe erosion caused by the impact of large water born debris.

Other applications

These include machine tool frames, lighting poles, water and oil tanks and concrete repairs, shingles, roof tiles, prefabricated shapes, panels, shotcrete, curtain walls, slabs on grade, precast elements, composite decks, vaults, safes, impact resisting structures and offshore structures, structures in seismic regions, thin and thick repairs, crash barriers, and footings [6].

2.7. Natural fiber reinforced concrete

Natural fiber reinforced concretes are concretes reinforced with naturally occurring fibers. Some of the best known natural fibers are sisal, coconut, sugarcane bagasse, plantain (banana), palm, etc. There are two types of natural fibers which are unprocessed and processed natural fibers.

2.7.1. Unprocessed natural fibers

These fibers can be obtained at low levels of cost and energy using locally available manpower and technical know-how. These fibers are typically referred to as unprocessed natural fibers (UNF).

Straw reinforced, sun-dried mud bricks for wall construction and horse hair in mortar are typical examples. There are some deficiencies in their durability which results from the reaction between the cement paste and the fibers and swelling of the fibers in the presence of moisture. The mechanical properties of the unprocessed natural fibers are presented below.

a) **Coconut fiber**- has an outer covering made of fibrous material. This part of the coconut called the husk consists of a hard skin and a large amount of fibers embedded in a soft material. It can be extracted simply by soaking the husk in water to decompose the soft material surrounding the fibers. This process called retting is widely used in the less developed countries.

b) **Sisal fibers**-In Australia, these fibers have been successfully used for making gypsum plasters sheets. A considerable amount of research has been carried out in Sweden for developing good quality concrete products reinforced with this fiber. Sisal fibers are stronger than most of the other natural fibers.

c) **Sugarcane bagasse fiber**- is the residue remaining after the extraction of the juice and contains about 50 percent fiber and 30 percent pith with moisture and soluble solids consisting the remaining 20 percent. Its properties depend on the variety of the sugar cane, its maturity and on the efficiency of the milling plant.

d) **Bamboo fiber**- belongs to the grass family and can grow to a height of 50ft (15m) with diameter varying within the range of 1 to 4 in (25 to 100mm). They can be fabricated to form a continuous reinforcing material for concrete. They are strong in tension having a high water absorption capacity, low modulus of elasticity, and special equipment may be needed to extract from the stems.

e) **Flax**-is a slender and erect plant grown mainly of its fiber. It has extremely high tensile strength and modulus of elasticity compared to those of other natural fibers.

f) **Other vegetable fibers**-Only few vegetable fibers have been found to be potentially suitable as reinforcing materials. These fibers are removed manually from the stem of the plant.The jute fiber is explained briefly at the next section of this chapter.

Constituents of the unprocessed natural fiber reinforced concrete

1. **Cement**- The cement must meet the ASTM standard specification C150 or C595 and type III (high-early strength) is recommended to reduce hardening retardation caused by the glucose present in most natural fibers.
2. **Aggregates** – The aggregates must meet ASTM C33 gradation requirements.
3. **Water and admixtures** – The water should be clean and good quality. Admixtures such as accelerating agents may be used to decrease the influence of the glucose retardant. If mild steel rebar are not used as additional reinforcement, calcium chloride could be used. Water reducing admixtures and high range water reducing agents can be added to increase the workability when plastering. And also bacterial attack of organic fiber is prevented with the use of organic-micro biocide.

4. **Fibers**- The length of fibers may vary from 1 to 20in (25 to 500mm). Because fibers are natural materials, they are not uniform in diameter and length. Typical values of diameter for unprocessed natural fibers may vary from 0.004 to 0.03 in (0.1 to 0.75 mm).[8]

Table 2. 2. Typical properties of natural fibers [8]

Fiber type	Coconut	Sisal	Sugarcane bagasse	Bamboo	Jute	Flax	Elephant grass	Water reed	Plantain	Musamba	Wood fiber (Kraft pulp)
Fiber length, in	2-4	N/A	N/A	N/A	7-12	20	N/A	N/A	N/A	N/A	0.1-0.2
Fiber dia. In.	0.004-0.016	N/A	0.008-0.016	0.002-0.016	0.004-0.008	N/A	N/A	N/A	N/A	N/A	0.001-0.003
Specific gravity	1.12-1.15	N/A	1.2-1.3	1.5	1.02-1.04	N/A	N/A	N/A	N/A	N/A	1.5
Modulus of elasticity, ksi	2,750-3,770	1880-3770	2175-2750	4780-5800	3770-4640	14500	710	750	200	130	N/A
Ultimate tensile strength, psi	17,400-29,000	40000-82400	26,650-42,000	50750-72500	36250-50750	145000	25800	10000	13300	12000	101500
Elongation at break, percent	10-25	3-5	N/A	N/A	1.5-1.9	1.8-2.2	3.6	1.2	5.9	9.7	N/A
Water absorption, percent	130-180	60-70	70-75	40-45	N/A	N/A	N/A	N/A	N/A	N/A	50-75

Note N/A = Properties not readily available or not applicable

Metric equivalents 1in= 25.4 mm; 1ksi =1000psi= 6.895 MPa

Table 2. 3. Mechanical properties of several types of fibers of unprocessed natural fibers [8]

Type of fiber	Average diameter in.	Average length, in.	Absorption after 24 hr, percent	Average fiber density (SG)	Average tensile strength,psi	Average bonding strength,psi	
Bagasse	0.02	1.38	122.5	0.639	3570	36	N/A
Coconut	0.027	11.02	58.5	0.58	8825	40	2600
Jute	0.004	15.75	62	1.28	53500	20	N/A
Maguey	0.014	15.75	63	1.24	54400	N/A	N/A
Lechuguila	0.014	15.75	102	1.36	54100	N/A	N/A
Banana	0.011	3.7	276	0.298	10960	35	3.000
Guaney (palm)	0.017	17.44	129.9	1.195	50000	40	2.880
Bamboo	Variable	variable	51	0.72	54680	45	1.800

Note N/A = Not available

Methods of mixing

- Wet mix
    - A low volume fraction of fibers used
    - Water to be added to the mix has to take into account the high natural water content in the natural fibers.
    - The mixing procedure must comply with ASTMC94 process and portions of ACI 304 recommendations. The procedure is to add cement with water and additives to form slurry. Then the fine aggregates are added and finally fiber is added and dispersed into the slurry.
    - The sampling must comply with ASTM practice C172 and C685.
    - ASTM C39 and C78 are to be followed for compressive and flexural strength testing.
- Dry compacted mix
    - is used for industrial or semi-industrial projects
    - The volume fraction used is about 10 times the volume fraction used in the wet mix.
    - The fibers are in a SSD state.
    - The recommended mixing procedure is to add fibers in SSD condition to cement and aggregates and then add a very limited amount of water.
    - Mixing can be done by hand, and according to ASTMC94.
    - As wet mix the compressive and flexural strength testing ASTM C39 and ASTM C78 are to be followed.
    - Casting is made with pressure application because very little or no water is added to the mix

The volume percentage of unprocessed natural fibers used in a mix varied from 3 to 30 percent depending on the type of fiber used and the manufacturing procedure.

Table 2. 4. Mix proportions for wet mix and dry compacted mix of unprocessed natural fibers[8]

Ingredients	Wet mix	Dry-compacted mix
Cement fiber, lb/yd^3	925-1000	880-925
Coconut fiber, lb/yd^3	30	370

Sand,	2500	2500
Water -in fiber lb/yd^3 -added lb/yd^3	3.5 (estimate of natural condition) 630	460 (estimate of saturated-surface-dry condition) 800
Additives -Calcium chloride,lb -Microbiocide, oz -Water reducers	 35 1.9 none	 35 2.1 none

Metric equivalents; 1lb/yd3 =0.593kg/m3; 1lb=0.454kg; 1oz = 28.35g

Factors affecting properties of unprocessed natural fiber reinforced concrete

There are factors that affect the properties of unprocessed natural fiber reinforced concrete. The type and length of fibers as well as volume fraction are the most significant factors.

The workability is reduced due to the increased surface area and water absorption of the fibers by the addition of unprocessed natural fibers to concrete. Test results show that for natural fibers the minimum fiber addition to provide some improvement in the mechanical properties of the cement composites is about 3 percent by volume. The impact resistant is increased in most cases regardless of the fiber volume fraction, but other properties are not improved significantly and remain similar to plain concrete.

A mix that is too stiff or too dry could make the final product inadequately compacted which contain voids or honeycombs. A mix that is too wet should reduce strength. The mix should have a uniform dispersion of the fibers in order to prevent segregation or balling of the fibers during the mixing. Therefore, the fibers are to be distributed in such a way to allow them to perform their desired functions and to achieve a composite action between the fibers and the matrix by ensuring adequate interfacial bond. Balling should not be allowed to occur as it has a detrimental effect on the strength. Most balling occurs during the fiber addition process. Increase of aspect ratio, volume percentage of fiber, and size and quantity of coarse aggregate will intensify the balling tendencies and decrease the workability. To coat the large surface area of the fibers with paste, experience indicated that a water cement ratio between 0.4 and 0.6 and minimum cement content of 400 kg/m are required. Certain mixing method can be employed to minimize the balling effect. Normally, the progressive addition of fibers at the end of mixing process, after the other ingredients have been mixed, reduces the balling effect. Also the use of high-range water reducing admixtures is found to substantially increase workability without adversely affecting strength.

Compared to conventional concrete, fiber reinforced concrete mixes are generally characterized by higher cement factor, higher fine aggregate content and smaller size coarse aggregate. Depending up on the amount of fibers and the method of mixing (dry batch or wet batch), unit weight may be reduced to 94 lb. /ft^3(1500 kg/m^3) compared to normal concrete which is 145 to 155 lb./ft^3 (2300 to 2500 kg/m^3). The workability of the dry-compacted mix is normally poor.

A fiber mix requires more vibration to consolidate the mix. External vibration is preferable to prevent fiber segregation. Metal trowels, tube floats, and rotating power floats can be used to finish the surface.

Another aspect is strength of the concrete. Since the unreinforced cement mortar matrix posse’s adequate strength for many applications, but is brittle it is customary to study the influence of fibers on the increased ductility that can be achieved. Apart from strength, other aspects such as deformation under load (stiffness), durability, cracking characteristics, energy absorption, water tightness and thermal properties should also be evaluated. The most important contribution of the fibers can be rationally evaluated by determining the fracture toughness of the composite.

Compressive strength is not significantly affected by the addition of fibers, while tensile and flexural strength and toughness are all substantially increased. Furthermore for a particular fiber there exists an optimum value for both volume fraction and fiber length.

A successful construction material should possess desirable serviceability characteristics in addition to strength. The amounts of available test data on the durability of unprocessed natural fiber reinforced concrete are limited. The following observations are nevertheless made based on literatures.

a) Unprocessed natural fibers are more vulnerable than other fiber reinforced concretes in terms of durability. The highly alkaline pore-water in the concrete seems to deteriorate the fibers.

b) Durability can be substantially improved by replacing 40 to 50 percent of the cement with silica fume, since the addition of silica fume reacts with lime and considerably reduces the alkalinity of the pore-water.

c) Improved durability can be achieved by coating the fiber with suitable chemicals such as formic and stearic acid.

The placing and finishing of the unprocessed natural fiber reinforced concrete is dependent on the method of mixing used (wet mix or dry compacted mix]. Placing of the wet mix may be achieved by conventional agreement. Internal or external vibrators should be used by the slump test or the k-stump tester as per the ASTM recommended penetration test. Air content in the mix can be measured using ASTM C 231 or C173.

Table 2. 5. Factors affecting properties of natural fiber reinforced concretes

Factors	Variables
Fiber type	Coconut, sisal, sugarcane bagasse, bamboo, jute, wood, vegetables (akwara, elephant grass, water reed, plantain, and musamba)
Fiber geometry	Length, diameter, cross-section, rings and hooked ends
Fiber form	Mono-filament, strands, crimped, and single-knotted
Fiber surface	Smoothness, presence of coatings
Matrix properties	Cement type, aggregate type and grading, additive types
Mix proportioning	Water content, workability aids, defoaming agents, fiber content
Mixing method	Type of mixer, sequence of adding constituents method of adding fibers, duration and speed of mixing
Placing method	Conventional vibration, vacuum dewatering for sprayed-up member, vacuum-press dewatering for slurry-dewatered member, extrusion and guniting
Casting technique	Cast pressure
Curing method	Conventional, special methods

For placing the dry-compacted mix, there is a need for a special type of formwork since the mix is dry and has to be compacted with some pressure within the formwork. Once the dry mix is placed inside the formwork, it is subjected to a confining pressure of about 30 to70 psi (0.2 to 0.5

MPa). This confining pressure is applied for a period of about 24 hours. Care should be taken not to apply a larger pressure than needed. Since water (which is critical for hydration) may be squeezed out. The air content of the mix can be obtained using ASTMC 231 or ASTMC 173. The unite weight can be obtained using ASTMC 130.

2.7.2. Processed natural fibers

Processed natural fibers (PNF) are fibers derived from wood by chemical process such as the Kraft process. Kraft pulp fibers are used in sophisticated process such as the Hatschek process to produce thin sheet high fiber content FRC. These fibers have been used in commercial production for the manufacture of thin-sheet fiber reinforced cement products.

Plant materials are processed to extract the fibers which are referred as pulping and trees are the principal plant materials used for pulping. Breaking of the bond between fibers in solid softwoods and hardwoods is involved in pulping. It is classified as either full-chemical, semi-chemical or mechanical depending on the nature of defiberization process. In chemical pulps the wood is chipped where as in mechanical pulps the wood is grinded. Semi-chemical pulps are made with a combination of chemical cooking which softens the fiber followed by mechanical treatment to separate the fibers. The wood that are removed in the chemical process are susceptible to alkalis and degrade the unprocessed natural fiber reinforced cements and concretes. Thus chemical (Kraft) pulps are more commonly used for the reinforcement of cement.

The commonly used method for the production of processed fiber cement and concretes is the slurry-dewatering technique. In this method the fibrous cement product is formed from a dilute slurry (about 20 percent solids) of fiber-cement or fiber-mortar. The excess water is removed from the slurry by applying vacuum dewatering and pressure. The product is then cured in air or in an autoclave to develop its strength and other mechanical properties.

Hand methods can also be used. In this case, the fiber is rolled by hand into a slurry of cement and fine sand and compacted by rolling with a toothed roller. This method is not appropriate for manufacture of Kraft wood pulp reinforced boards since the fibers are not long enough.

The flexural performance of cementitious materials resulting from Kraft pulp fiber reinforcement is improved. In the case of slurry –dewatered wood fiber reinforced cement, the density of the composite decreases and its water absorption capacity increases with increasing the fiber content increases. The increase in moisture content tends to decrease the flexural strength and increase the flexural toughness of the composites.

2.8. Jute fiber reinforced concrete

Jute fiber reinforced concrete is a concrete repair composition including an aggregate, a binder, and fiber reinforcement, where the fiber reinforcement includes jute fiber.

Jute is a bast fiber which is a long, soft, shiny fiber that can be spun into coarse, strong threads. It is used for sacking, burlap, and twine as a backing material for tufted carpets. It is the second most produced and useful after cotton which is one of the cheapest natural fibers. It has the highest average tensile strength after bamboo, Maguey and Lechuguila. Jute fiber has also the highest modulus of elasticity after Bamboo. Jute fibers are composed primarily of the plant materials cellulose, lignin, and pectin. Both the fiber and the plant from which it comes are commonly called jute. It belongs to the genus Corchorus in the basswood familyTiliacia.

Fig 2. 2. Jute fiber

2.8.1. Physical properties of jute fiber

1. Ultimate length= 1.5-4mm
2. Ultimate diameter =0.015-0.02mm
3. No. of ultimate in x-section= 6-10
4. Fibers length = 5-12ft

5. Color= white, off white, yellow, brown, grey, golden
6. Strength (tenacity)= 3-4 gm/den
7. Elongation= 1.7% ate the break
8. Specific gravity=1.5
9. Moisture regain (MR%)= 13.75%
10. Resiliency= bad
11. Dimensional stability = good
12. Abrasion resistance = average
13. Effect of light and heat= average
14. Effect of microorganism= good (better than cotton)

2.8.2. Chemical properties of jute fiber

1. Effect of acids = easily damaged by hot dilute acids and conc. Cold acid
2. Effect of alkalis= fibers are damaged by strong alkali. Fibers losses weight when it heated with caustic soda
3. Effect of bleaches= resistant to bleaching agents (bleaching agent, H2O2, NaOCl, Naclo2, Na_2O_2, CH_3COOH, $KMnO_4$, etc.)
4. Effect of light = color changes slightly in presence of sun light. It happens due to presence of lignin in fiber
5. Effect of mildew =prevention ability is better than cotton and linen
6. Dyeing ability = easy to dyeing. Basic dye is used to color jute fiber [10]

2.8.3. Use of jute fiber

Jute is the second most important natural fiber after cotton, it has various uses like

- Making cloth for wrapping bales of raw cotton, and to make sacks and coarse cloth.
- Making curtains, chair coverings, carpets, area rugs, hessian cloth, and backing for linoleum.
- Jute is biodegradable in nature then this could be a substitute where synthetic fiber is unsuitable.

- Traditionally jute was used in traditional textile machineries as textile fibers having cellulose (vegetable fiber content) and lignin (wood fiber content). Furthermore jute and its allied fibers is started to be used for the automobile, pulp and paper, and the furniture and bedding industries with their non-woven and composite technology to manufacture nonwovens, technical textiles, and composites.

- Jute can be used to create a number of fabrics such as Hessian cloth, sacking, scrim, carpet backing cloth (CBC), and canvas.

- Hessian, lighter than sacking, is used for bags, wrappers, wall-coverings, upholstery, and home furnishings.

- Consumers are using jute products for espadrilles, floor coverings, home textiles, high performance technical textiles, composites, and more.

- Jute is also used in the making of ghillie suits which are used as camouflage and resemble grasses or brush

Thus, jute is the most environment-friendly fiber because it has a low carbon foot print and the expired fibers can be recycled more than once. And also jute gives geotextile products making the agricultural commodity more popular in the agricultural sector. It is used for soil erosion control, seed protection, weed control, and many other agricultural and landscaping uses. It can be used more than a year and when left to rot on the ground makes the ground cool and fertile. Generally jute is good for the air, soil and it is a source of wood pulp. [10, 18]

2.8.4. Properties of jute fiber reinforced concrete

Regarding the workability of jute fiber reinforced concrete T. Sai and B Manoj studied about the behavior of jute fibers mixed in concrete as reinforcement material with different volume of fraction of fiber content and results have shown that as the content of jute fibers increases, the slump value i.e. workability of concrete decreases.

The effectiveness in improving strength varies among compression, tension, shear, torsion, and flexure as discussed below.

a. Compression

The compressive strength is increased with addition of jute fiber to the concrete having small length and smaller fiber content. When a high volume and larger length of yarn is added difficulties encountered to maintain consistency in concrete mix. Since numerous studies have considered reinforcing material that is fibers or yarns as similar to coarse aggregate, the inclusion of jute yarn leads to an increase of coarse aggregate fractions (fiber agglomeration) in spite of the fiber aggregate fraction which could result in a high porosity in the cement matrix. For decreasing trend with yarn content can be explained that with the addition of jute yarn in concrete reduces the specific gravity of the composites and due to the low specific gravity, inadequate mixing and high porosity of the Jute yarn reinforced cement concrete, a lower compressive strength with respect to the reference concrete particularly when a high volume and larger length of yarn was added. Similar results were obtained by Shimizu and Jorillo (1992). However the short yarn length with smaller content which act as short jute fiber was firmly bound the composite constituent and develop an intact material which results the more resistance to applied force. The long and higher volume fractions were found to ball up during the mixing process. The process called 'balling' occurs and causes the concrete to become stiff and a reduction in workability with increased volume dosage of fibers. Thus this causes variation in strengths when subjected to loading. [2, 3]

Different failure modes are observed after sample testing of compressive strength. In case of control specimen, it was seen that the crack propagates rapidly with a regular manner while the cracks were observed to run in multi directional path for jute yarn reinforced concrete. This is possible through stress transfer across the cracks and the fiber arrests the rapid crack propagation and prolongs the strain life to continue beyond the ultimate. [12]

Jute fiber reinforced concrete behaves as a homogeneous material within certain limits. The random distribution and high surface - to - volume ratio (specific surface) of the fibers results in a better crack arresting mechanism. With low fiber contents that are normally used in cement composites (from 2 to 4% by volume), the strain at which the matrix cracks is little different from that of plain concretes. However once cracking occurs, the fibers act as crack arresters and absorb a significant amount of energy as they are pulled out from the matrix without breaking. The inclusion of short jute fibers in cement based matrices nevertheless increases the first crack strength and once the matrix has cracked, the fibers carry a major portion of the tensile stress in the composite material. [2]

Rahul et al. have seen improvement of compressive strength using quantity of jute as 1 % of cement being chemically treated. [14]

T. Sai & B. Manoj studied on the behavior of jute fibers mixed in concrete as a reinforcing material for improving the mechanical properties of concrete and 1% jute content cured up to 56 days has significant improvement of compressive strength with respect to ordinary concrete. [16]

Mohammad et.al. studied the effect of introducing jute yarn on the mechanical properties of concrete and 33% increment of compressive strength was seen as a maximum value with respect to concrete without jute yarn.[12]

Basudamet. al. developed an optimum length of 5mm and volume fraction of jute fiber to be 1 weight percent jute fiber loading and improvement of 60% compressive strength to concrete without jute fiber reinforcement. [3]

b. Direct tension

The brittleness and low tensile strength of concrete make it abortive to struggle with the direct tension. Hence the measurement of tensile is obligatory to determine the load at which the concrete members may crack; therefore the cracking is due to the tension failure.

The tensile load for a jute fiber reinforced cement composite is very much dependent on response of a composite to tensile loads and also is very dependent on the strength properties of the reinforcement fibers, since they are high compared to the resin system on its own. Comparatively lower values for the composite are synthesized due to the non-uniform stress transfer due to the random orientation of the fibers in the matrix. Fiber agglomeration happens in the matrix and the formation of air gaps also contributes to reducing the properties of the composite. [2, 12]

The short jute fiber with lower content is more promising than the longer fiber with more amounts for concrete reinforcement. The short fiber cut with lower content influences the proper distribution of fiber and resist cracking the cylinder against the tensile load. The multiple cracks was found in the cylindrical specimen during tensile failure of jute fiber reinforced concrete, while plain concrete exhibits the single and rapid crack, thus the composite shows the enriched tensile value with smaller volume content of fibers. The contribution of the jute fiber is observed on the ability of jute fiber reinforced cement concrete composite to maintain the ultimate mode through further deflection without sudden collapse. Larger fiber content yields more voids in the concrete due to the lack of free organization of the concrete matrix as a result of the reduced workability and balling effect during vibration and casting of specimens.

The first crack load of fiber reinforced concrete depends basically on the amount, length and configuration, strength and ductility of fibers, whereas cement content and aggregates are less responsible in this concern. The contribution of the jute fiber is observed on the ability of jute fiber reinforced concrete composite to maintain the ultimate load through further deflection without sudden collapse.

Rahul et al. also have seen improvement of tensile strength using quantity of jute as 1 % of cement being chemically treated. [14]

There has also been seen an improvement of tensile strength using 1% jute content cured up to 56 days with respect to ordinary concrete. [17]

23% of tensile strength improvement has also been seen as a maximum value introducing jute yarn to the concrete by Mohammad et.al. [12]

c. Flexure

The four point bending strength test of the jute fiber reinforced concrete specimens showed a result of increment initially and a decrement with further increase of fiber content. During bending test, when a crack was generated in the matrix, the randomly distributed jute fibers provided a bridging effect to the matrix. At this portion of the tensioned composite all the stresses were transferred from the matrix to the fiber and may be this phenomenon is responsible for carrying the increased loads. At the beginning of loading, the behavior is elastic in nature until the first crack was generated and then the failure of the specimen was gradual. The specimen did not break in to pieces after occurrence of excessive vertical cracks, compared with the control concrete having no fiber. The decrement of the strength is caused by the balling of jute yarn reinforced cement concrete which creates high porosity and weak zones in the specimen. [3]

Failure of such beam specimen are initiated by the formation of cracks that would proceed along the pre-weak zones with smaller cracking load as compared with the intact specimen or with specimen with lower yarn content. The matted condition of concrete mixture is irradiate by using low reinforcing material cut length and jute spun yarn as reinforcing material. During the mixing of concrete low cut lengths jute yarn de-twist slowly and causes the even spreading of fiber and create the better reinforcement on composites.[12]

The same outcome was observed by Mohammed et. al. that adding larger fiber content and larger length resulted the easy failure of the concrete. Mixing of concrete low cut length's jute fiber can move easily and causes the even spreading of fiber and create the better reinforcement on composites. However the higher porosity and uneven distribution of reinforcing material causes the heavy reduction of bending strength. Moreover, the inclusion of more jute of larger length results to the discontinuity of concrete mixing and improper arrangement of the concrete constituents that highly affects the strength against bending of a prism specimen. [12]

Flexural modulus indicates stiffness as well as the extent of deformation of a material when it is subjected to the bending stress and gives a measure of the ductility of the material the ductile materials have a lower flexural modulus as it undergoes a considerable deformation before failure happens whereas brittle materials have a high value of flexural modulus as it fails before undergoing deformation.

Toughness is defined by the total energy absorbed prior to complete separation of the specimen is given by the area under load-deflection curve. Toughness or energy absorption of concrete is increased considerably by the addition of fibers. The toughness index is calculated as the area under the load deflection curve up to the 1.8mm deflection divided by the area up to the first crack strength (proportional limit). All specimens made of plain concrete failed immediately after the first crack and hence the toughness index of these specimens is equal to 1. The addition of fibers increases the toughness index.

T. Sai & B. Manoj also observed significant improvement of flexural strength introducing 1% jute content mixed in concrete with respect to ordinary concrete. [17]

Mohammad et.al. also found 23% increment of flexural strength as maximum value introducing jute yarn to the concrete.[12]

Basudamet. al. also observed improvement of 66% in flexural strength to concrete without jute fiber reinforcement with an optimum length of 5mm and volume fraction of jute fiber to be 1 weight percent jute fiber loading. [3]

CHAPTER THREE

MATERIALS AND METHODS

3.1. Materials Used

In developing the concrete mix, it is important to select proper ingredients and evaluate their properties. The materials used for this investigation were cement, fine and coarse aggregate, jute fiber and water.

3.1.1. Cement

Cement is the most common binding material used in concrete production. The cement used in this study is Portland pozollana cement of grade 32.5R, CEM 11 confirming to IS certified number 120003 supplied by Muger cement factory. Portland cement is a finely ground grey powder chemically formed by combining raw materials containing calcium oxide(CaO), silica (SiO_2), alumina(Al_2O_3), and iron oxide (Fe_2O_3), heating this mixture to a high temperature, and then grinding the resulting material called clinker, with a small quantity of calcium sulfate ($CaSO_4$). The cement for entire experiment was procured in a single consignment and stored properly.

3.1.2. Fine aggregate

Locally available fresh river sand, free from organic matter was used as per IS 456-2002. The test for determination of specific gravity was carried out. The surface dry aggregate were used for test. These properties of aggregate are necessary to decide proportion of the concrete mix. The sand was air dried and free from any foreign material, earlier than mixing.

3.1.3. Coarse aggregate

Locally available good quality coarse aggregate from crushed ballast rock is used. The size of coarse aggregate varies from 10mm to 20mm, means the material passed from 20mm IS sieve bur retained in 10mm IS sieve. The aggregates were free from adherent coating, injurious amount of disintegrated pieces, alkali, vegetable matter and other deleterious substances. Care was taken that the aggregate don’t contain high concentration of flaky, elongated shapes and organic impurities which might affect the strength or durability of concrete.

3.1.4. Jute fiber

Jute is a natural fiber. Jute fibers were collected from local market called ‘menealeshtera’. , The length of jute used in the reinforced concrete is 5mm, 15mm and 25mm manually cut by scissor. The raw and cut jute fiber is presented in Fig 3.1.

Fig 3. 1. Raw and cut jute

3.1.5. Water

The quality of water is important because contaminants can adversely affect the strength of concrete and cause corrosion of the steel reinforcement. Water used for producing and curing concrete should be reasonably clean and free from deleterious substances such as oil, acid, alkali, salt, sugar, silt, organic matter and other elements which are detrimental to the concrete. Hence potable tap water was used in this study for mixing and curing.

3.2. Experimental Procedure

3.2.1. Experimental Design

The main target of this study is to produce jute fiber reinforced concrete made with locally available jute fiber then to characterize its properties, especially the mechanical properties in the hardened state. Literature review reading was made for providing understanding of jute fiber reinforced concrete focusing on its mechanical properties, fresh properties, durability, mix design consideration, placing and finishing and its practical applications. The currently available and modified test methods used to evaluate the compressive, flexural and tensile strength of jute fiber reinforced concrete were studied. Material collection was made after the literature review has been made.

A trial mix proportions were used for mix of conventional concrete to achieve C30. The jute fiber was added on the basis of percentage to cement content of conventional concrete. C30 grade of concrete were designed to give a slump value of 25-75mm and a 28 day compressive strength of 30MPa.

Cube, cylinder and prism molds of size 15cmx15cm, 6-inch dia. and 12-inch height, and 10cmx10cmx50cm respectively were casted. The molds were oiled properly prior to the casting of the specimens.

The high strength of C30 concrete grade was produced using two mix series besides the control mix; one incorporating 0.5%, 1.0% and 2% enclosed with fiber length of 5mm each and the other with length of 5mm, 15mm and 25mm incorporated with 0.5% volume each. The chosen length and volume percentage of fiber is based on the recommendation given by the report of ACI committee for unprocessed natural fiber, research made by professor Basudam et.al. on the development of jute fiber reinforced cement concrete composites, research made by Rahul et.al. on the use and development of jute fiber in reinforced cement concrete grade M40, research made by T. Sai et.al. on a comparative study of jute fiber reinforced concrete with plain cement concrete and research made by Mohammad et.al. on the effect of jute yarn on the mechanical behavior of concrete composites.

As already discussed in the other chapters, the main factors controlling the mechanical performance of the obtained composite materials are the properties of the fibers and the matrix, as well as the bond between them. For this reason, investigation of the properties of the constituent material and preliminary characterization of jute fibers were made to obtain the necessary data about their geometric and mechanical properties. Tests were conducted on the constituent material to determine the gradation and physical properties of fine and coarse aggregate.

The mixing was made in dry state. Trial batch were made at first. The chopped jute fibbers were made in a saturated surface dry condition. The mixing procedure was first addition of fiber in SSD condition to the cement and aggregates and a very limited amount of water was added. Mixing was done by hand at first and then by the mixer as per ASTM C94. The dry mix samples were casted followed by the application of pressure since limited amount of water was added to the mix. All the specimens were demoulded after 24hr of casting and water cured for 14 days respectively. At the specified date they were removed from water, surface dried and tested. Each test result represented the mean of three specimens of cube and cylinder each and two specimens of beam. The schematic flow diagram of jute fiber reinforced concrete fabrication is presented in Fig. 3.2.

Proportions of these mix series along with the volume of percentage of fiber contents and length of fiber are presented at Table 3.1. The mixes are designated in such a way that the first and second letters and subscripts describe the length and volume portion of the fiber used in the concrete matrix. Each mix series was coded.

Table 3. 1. Mix proportions for the four mixes

Mix designation	**Cement quantity(kg/m^3)**	**W/C Ratio**	**Water (liter/m^3)**	**Fine aggregate (kg/m^3)**	**Coarse aggregate (kg/m^3)**	**Jute fiber(kg/m^3)**
Control	430	0.45	195	462	1274	0
$L_5V_{0.5}$	430	0.45	195	462	1274	215
L_5V_1	430	0.45	195	462	1274	430
L_5V_2	430	0.45	195	462	1274	860
$V_{0.5}L_5$	430	0.45	195	462	1274	215
$V_{0.5}L_{15}$	430	0.45	195	462	1274	215
$V_{0.5}L_2$	430	0.45	195	462	1274	215

For instance, a concrete mix designated by $L_5V_{0.5}$ is considered as a concrete mix with length 5mm which incorporates 0.5% of fiber volume and $V_{0.5}L_{15}$ designate concrete mix incorporating 0.5% of fiber volume with length of 15mm. the ratio of cement, sand and coarse aggregate were 1: 1.07: 2.96. The water content to cement ratio used for the mix was 0.45.

Then the performances of unreinforced concrete were evaluated in order to better appreciate the improvement gained by the addition of fibers. Thereafter, the slump test and fresh density in the fresh state, as well as compressive strength, tensile strength and flexural strength in the hardened state were evaluated for each mix, varying the volume fraction and length of fibers.

The test results were then discussed and analyzed after carrying out the tests. Conclusions and recommendations for further studies are provided.

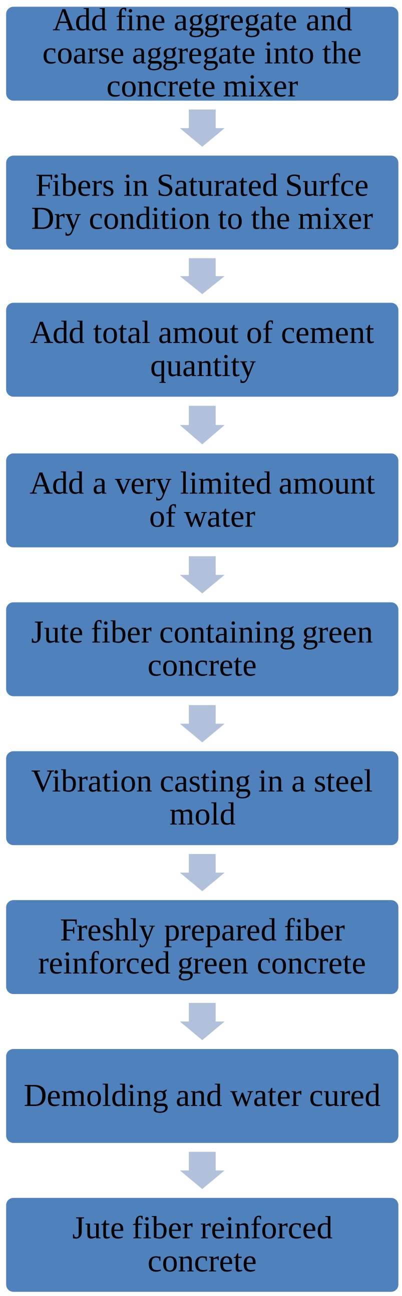

Fig 3. 2. Schematic flow diagram of jute fiber reinforced concrete fabrication

3.3. Testing procedure

3.3.1. Testing of fresh concrete

Slump test in accordance with the standard ASTM C995-94 was performed for each mix in the fresh state. The fiber reinforced mixes gave slump test results varying from zero to a few centimeters; however the mixes responded well to mechanical vibration and placed and compacted without much effort.

Slump cone test were carried out to obtain the workability and consistency of fresh concrete. The obtained uniform distribution of the fibers in the concrete and the ability of being successfully casted make the fiber reinforcement efficient. Each individual fiber needs to be coated with cement to give any benefit in the concrete. Standard users of fiber reinforced concrete indicated that adding more fibers in the concrete, particularly a really small diameter, results in greater negative impact on workability and the requirement for mix design changes. The slump changed because of the different type of fibers content and form. The lower slump result is the effect of addition of fibers which form a network structure in concrete thus restrains mix from segregation and movement. As results of high content and large area of fibers, fibers are certain to absorb more concrete paste wrap around and the increase viscosity of combination of mix the slump reduction.

3.3.2. Testing of hardened concrete

Compressive strength tests were carried out by oil pressure machine as shown in Fig 3.3,STYE-2000 digital display hydraulic compression testing machine [Zhejiang Tuagong Instrument Co., Ltd. (ISO 9001 certified] with soil penetration guage instrument capable of measuring deformation with a nominal capacity of 3000kN as per ASTM C39/ C 39 M-01. Weight of each specimen was measured before testing. The 14 days compressive strength of each mix was determined in accordance with the Ethiopian standard. The load was applied at a constant rate of 4.31kN/s. The rate of loading was taken not as required by the standard test method but it was adjusted by decreasing it for stress strain measurement. Since concrete is deformed with slow rate taking a long period of time, it could give good result .And the compressive strength was measured to the nearest two digits after a decimal. Average of the test results of three specimens belonging to a mix was accepted as a compressive strength of that mix for the testing day. Specimens were tested so that the direction of loading was 90 degree with the direction of casting.

Fig 3. 3. STYE- 2000 digital display hydraulic compression testing machine with soil penetration

Investigation of concrete's mechanical properties can be presented reasonably through the analysis of tensile strength. The brittleness and low tensile strength of concrete make it abortive to struggle with the direct tension. Hence the measurement of tensile strength is obligatory to determine the load at which the concrete members may crack therefore the cracking is due to the tension failure. The splitting tests (sometimes referred to as split tensile strength tests) are well known indirect tests used for determining the tensile strength of concrete. The test procedure consists of applying a compressive line load along the opposite generators of a concrete cylinder placed with its axis horizontal between the compressive planes. The splitting tensile strength test was conducted according to the test method ASTM C 496- 96.

Flexural tensile strength and energy absorption up to failure under flexural loading tests were carried out in the laboratory which was equipped with a STYE- 2000 digital display hydraulic compression testing machine [Zhejiang Tuagong Instrument Co., Ltd. (ISO 9001 certified] with soil penetration guage instrument capable of measuring deformation as per ASTM C78-00 except the loading speed is adjusted for the measurement of deformation of the concrete beam which is 0.39KN/S. Two points loading was used to determine the flexural tensile strength. Average of the results of the two beam specimens belonging to a mix were accepted as the flexural tensile strength. Specimens were tested so that the direction of loading was 90 degree with the direction of casting. The STYE-2000 digital display hydraulic compression testing machine is presented in Fig. 3.3.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Test results of fresh concrete properties

4.1.1. Slump test

Slump test is the common method of testing used to measure the workability of freshly mixed concrete. It measures the ability to be mixed, handled, transported and placed and consolidated with uniformity and minimum entrapped air. There are many factors influencing the workability property of jute fiber reinforced concrete such as the aggregate content, fiber geometry and volume fraction. Thus this study focuses on the influence of aspect ratio and volume fraction of fiber on the properties of fresh concrete.

The plain concrete (control mixes) were designed to give a slump of 25-75mm.The slump tests were performed on the fresh concrete for each mix and the slump values of the concretes vary between 0 to 45mm. The results are presented in Table 4.1.The test results showed that the presence of the jute fibers strongly affects the workability of the fresh concrete. The increment of the fiber length and volume of fraction decreases the workability especially for the 25mm fiber length concrete mix (highest length of jute fiber).The jute fiber made the compaction of the sample in the cone using the steel tamping rod for the slump tests difficult by resisting it. Thus the sample needed more compacting in the cone. Other than the plain concrete, the concrete mix with 0.5% fiber volume having 5mm length of jute fiber showed better workability. The slump values for the mixes reported in Table 4.1 and 4.2 are presented as a line graph at Fig 4.1.

It appeared that the jute fiber tend to make the mix stiff, unworkable and the materials tend to “hang together” and resist movement compared to the control mixes which results slump value reduction from the plain concrete. It made difficulty to work with fibers having higher aspect ratio and volume fraction. The stiffness led to an inadequately compacted final product which is likely to contain voids and honey.

The results confirmed as the study made by T. Sai and B. Manoj which stated that as the content of jute fiber increases the slump value decreases (section 2.8.4) which is similar to the literature

Table 4. 1. Results of slump values of mix series I

Mix Series I		
Concrete grade	Mix design	Slump Value(mm)
C30	Control-1	45
	$L_5V_{0.5}$	40
	L_5V_1	25
	L_5V_2	18

Table 4. 2. Results of slump values of mix series II

Mix Series I		
Concrete grade	Mix design	Slump Value(mm)
C30	Control-1	45
	$V_{0.5}\ L_5$	40
	$V_{0.5}\ L_{15}$	30
	$V_{0.5}\ L_{25}$	15

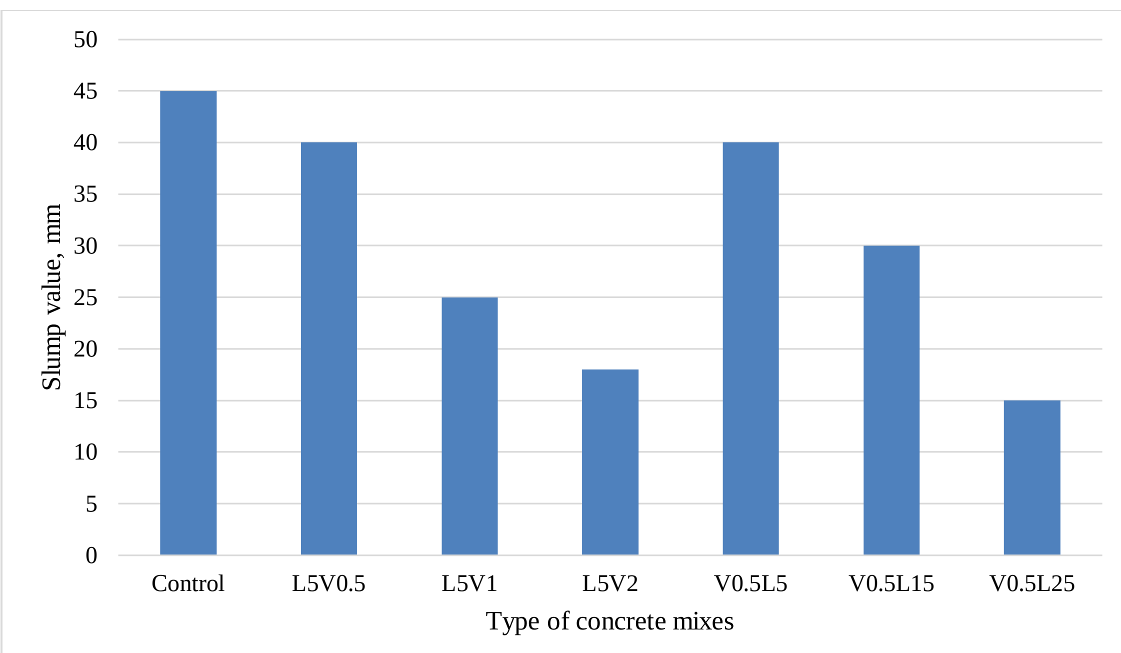

Fig 4. 1. Slump value of mix series I and II

review in section 2.7.1, and 2.5.5.It is also in harmony with the concept that a fiber mix generally requires more vibration to consolidate the mix.

Thus from the result, it was seen that as the content and length of jute fibers increases, the slump value which determines workability of concrete decreases.

4.2. Test results of hardened concrete properties

4.2.1. Compressive strength

The 14 days compressive strengths were determined with the measurement of deformation with load. The compressive strength representing the mean of three specimens with the standard deviation of the specimens and the relative strength gain or loss to the control mix is presented in Table 4.3.The raw data is attached in Annex C (Table A.3).

Table 4. 3. 14 day compressive strength results of mix series I

Mix Design	Mean 14th day Compressive Strength (MPa)	Standard deviation	Relative compressive strength, σ gain or loss (%)
Control	17.50	0.09	N/A
$L_5V_{0.5}$	23.30	1.00	33.14
L_5V_1	18.60	1.99	6.29
L_5V_2	16.70	0.57	-4.57

Table 4. 4. 14 Day compressive strength results of mix series II

Mix Design	Mean 14th day Compressive Strength (MPa)	Standard deviation	Relative compressive strength, σ gain or loss (%)
Control	17.50	0.09	N/A
$V_{0.5}L_5$	23.30	1	33.14
$V_{0.5}L_{15}$	12.92	1.19	-26.17
$V_{0.5}L_{25}$	11.50	0.31	-34.29

As presented in table 4.3 and 4.4, the 14^{th} day mean compressive strength for the plain control mix for both mix series is found to be 17.5 MPa. In the first mix series, addition of jute fiber of 5mm length and volume ranging from 0.5% to 2% results the mean compressive strength values ranging from 16.7MPa to 23.3Mpa with a maximum relative strength loss and gain of 4.57% and 33.14% respectively. A decrease in compressive strength was seen in mix L_5V_2 with a relative loss of 4.57% whereas the other mixes showed increasing results. The lowest strength value was noticed at the mix L_5V_2whereas the highest strength was seen in $L_5V_{0.5}$.In this mix series an increase in fiber volume has increased the compressive strength but a direct relationship with an increase of fiber volume and compressive strength was not noticed. The compressive strength is increased with increasing the volume percentage but above 0.5% fiber loading, it starts to decrease. Fiber loading 0 to 1% volume fraction increases the compressive strength and above 1%, it starts to decreases from the control mix. (See Table 4.3 and Fig 4.2).

Since the same constituents are used in the mixes, the control mix is the same for both the mix series which has 17.5MPa strength. Compressive strength values ranging from 11.5MPa to 23.3MPa with a maximum relative strength loss and gain of 34.29% and 33.14% respectively was obtained by the inclusion of fibers of different length with constant 0.5% volume fraction of jute fiber. A decrease in the compressive strength was noticed in the two mixes,$V_{0.5}L_{15}$ and $V_{0.5}L_{25}$with a relative loss of 26.17% and 34.29% which is very significant. In the rest of the mix which is $V_{0.5}L_5$a significant increase, 33.75% was registered which has the highest compressive strength. A minimum compressive strength is exhibited in the mix $V_{0.5}L_{25}$. Thus, similar to that of mix series I a direct relationship with an increase of fiber length and compressive strength using constant fiber volume was not seen. Fiber loading 0 to5mmlength with 0.5% volume fraction increases the compressive strength but as the length is increased above 5mm, the strength starts to decrease from the control mix. (See Table 4.4 and Fig 4.2)

Thus from the two mixes, maximum strength is achieved with 5mm fiber length with 0.5% fiber loading and minimum strength with 25mm fiber length with 0.5% fiber loading.

The compressive strength is decreased with addition of jute fiber to the concrete having higher length and higher fiber content. This result is caused because of the reason that it maintains low consistency in the concrete mix. It leads to fiber agglomeration (balling) which results in high porosity in the cement matrix. It reduces the specific gravity of the composites and due to the low specific gravity, inadequate mixing and high porosity of the jute yarn reinforced cement concrete, a lower compressive strength with respect to the plain concrete is found. The short yarn lengths with smaller content which act as short jute fiber firmly bound the composite constituent and develop an intact material which results the more resistance to applied force. The balling causes the concrete to become stiff and a reduction in workability with increased volume dosage of fibers.

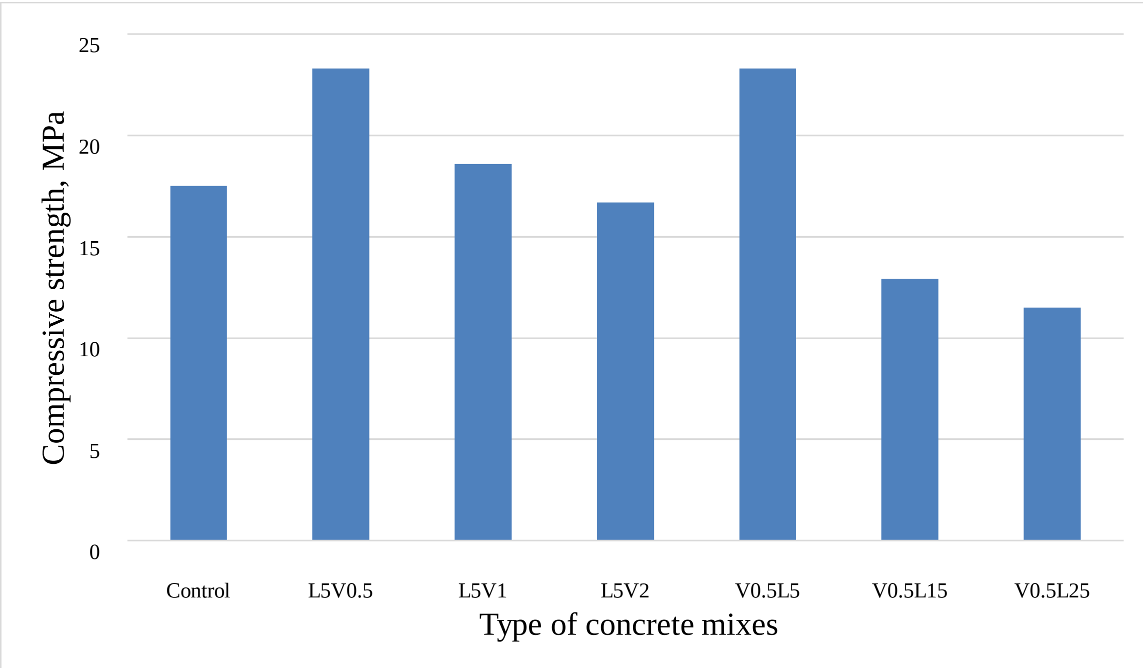

Fig 4. 2. Compressive strength values of mix series I and II

As the literature studies made by Rahul et.al and T. Sai and B. Manoj, the compressive strength is improved with the inclusion of jute fiber to the concrete mix. Mohammad et.al studies showed that 33% improvement of compressive strength was exhibited which is almost equal to this study which 33.75% improvement is made. But Basudam et.al improved the compressive strength by 60% which is much higher than this study. Therefore it can be concluded that the role of fiber in increasing strength is significant.

4.2.2. Stress-strain behavior of fibrous concrete

A complete stress-strain curve is needed for rational design and analysis of a concrete structure for proper design and rehabilitation. The brittleness of concrete and machine-specimen interaction makes it difficult to get a complete stress-strain curve of concrete. It needs special technique to get a full curve. It is well known that the stress-strain curve plays an important role on structural design and analysis; however no reliable stress-strain curves for jute fiber are currently available in the literature. The stress-strain curve is developed based on the deformations measured from the machine platens. The axial deformation has been used for test control. But for FRC, the large energy release during failure causes unstable descending branch. The ultimate concrete strain is required parameter and this is likely to be in the descending branch of the stress-strain curve, the complete stress-strain curve becomes necessary to design and analyze concrete structures.

Adding jute fiber to concrete also increases toughness. Toughness is defined as an ability of absorbing energy during loading. The toughness can be defined as the area under the stress-strain curve. Toughness ratio is used to quantify the effect of jute fiber on stress-strain curve. Tough higher amount of jute fiber increases ductility of concrete. The toughness of concrete is related to absorb energy in which the ductility is increased due to their energy absorption capacity. The jute fiber volume fraction and its aspect ratio play an important role in behavior of jute fiber reinforced concrete.

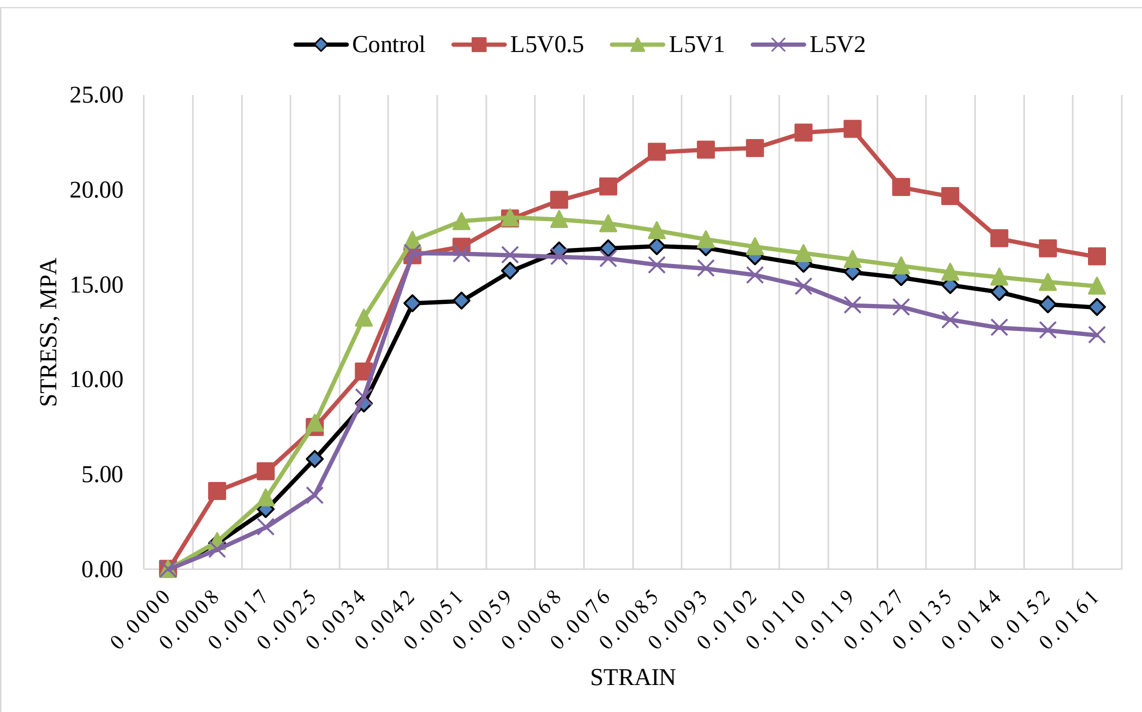

Fig 4. 3. Stress-strain graph of compressive strength test of mix series I

Figure 4.3 shows comparison of different fiber content mixing with the constant 5mm fiber length. The result shown in the graph seems to be unreasonable due to the problem is that the interaction between the testing machine and the specimen is unclear. After the specimen reaches peak strength, the load is decreased. However, the strain energy stored in the machine needs path to release. This causes an impulsive failure. In the case of FRC, it became worse that the strain energy is high.

Concrete is brittle and has very steep descending branch of the stress-strain curve. This causes explosive failure after peak and makes it difficult to get descending part because the strain change is small. To overcome brittle characteristics of high strength concrete, fiber has been used to improve the concrete. The capacity of a structure to absorb energy, with acceptable deformation and without failure is essential in seismic analysis. The addition of fiber has little effect on its pre-crack behavior but significantly improve post-crack response. One of the key difference between normal and fiber reinforced concrete is material behavior, which can be explained by its stress-strain curve.

Figure 4.4 shows comparisons of mixes with different fiber length having constant volume content. The addition of jute fiber to the concrete does not change the ascending branch (initial portion) but significantly changes the descending branch of the stress-strain curve. Thus the use of jute fiber in concrete significantly increases the ductility of concrete.

It was found that the total area under the curve of the jute fiber reinforced concrete with 5mm fiber length is larger than that of the plain concrete and concrete mix with other fiber length jute fiber. This shows the improvement of ductility of concrete with the addition of jute fiber. It is noted that the jute fiber volume fraction and its aspect ratio plays an important role in stress-strain behavior of jute fiber reinforced concrete as both the volume fraction of fiber and their aspect ratio lead to improvement.

The failure mode of jute fiber reinforced concrete shows that jute fiber reinforced concrete never completely collapse even after reaching a high strain curve.

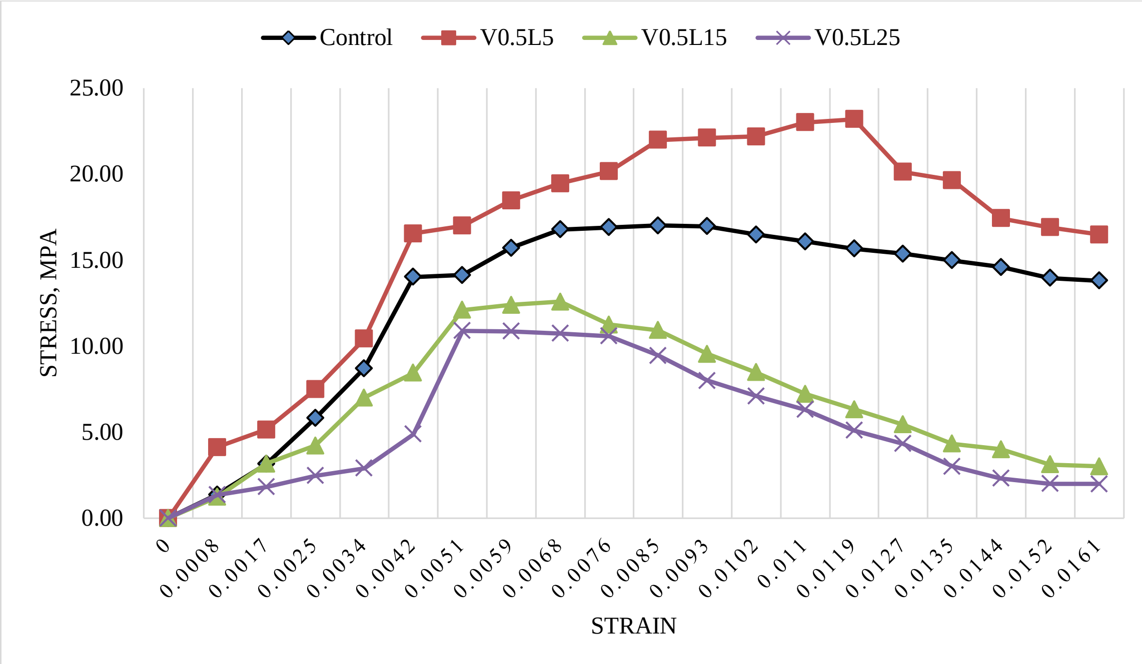

Fig 4. 4. Stress-strain graph of compressive test of mix series II

4.2.3. Strain at peak stress

The strain at ultimate stress is needed to design to specify failure allowed in concrete structure. The strain at ultimate stress is one of important parameters to get analytical stress and strain curve. But strain at ultimate stress depends on several testing conditions such as loading rate, type of aggregate, size and shape of specimen, and capping material. Adding jute fiber to concrete mix helps the FRC to sustain more deformation during loading. The fiber helps the structure to sustain larger deformation.

Figure 4.5 shows the strain at peak stress as a function of volume fraction and length of fiber. In mix series I, the strain at peak stress increases adding 0.5% and 1% volume fraction having 5mm length of jute fiber to the concrete mix. But further increment of volume fraction of jute fiber decreases the strain at peak stress. Excessive amount of jute fibers in concrete decreases the ductility of the concrete due to the harsh mix which causes non-uniform distribution of jute fiber.

In mix series II, the strain at peak stress increases with increasing the aspect ratio and volume fraction in the concrete mix up to 5mm and 0.5% respectively. The strain at the peak stress decreases adding above 0.5% fiber volume and 5mm fiber length to the concrete mix.

Thus it is clear that the addition of jute fiber is found to increase the strain corresponding to the peak stress which shows ductility improvement. 1.4% ductility improvement is achieved adding different volume fraction and length of fiber. The list of maximum compressive stress with strain at peak stress is found in Table 4.5 and 4.6. The raw data is presented in Annex C (Table A.8 and A.9).

Table 4. 5. 14 Day Strain at peak stress results of mix series I

Mix series I Specimen	Maximum compressive stress, f'c (Mpa)	Strain at peak stress, e_o
Control	17.01	0.0085
$L_5V_{0.5}$	23.20	0.0119
L_5V_1	18.54	0.0059
L_5V_2	16.66	0.0042

The inclusion of fibers in concrete is very much advantageous in delaying the materials failure and increasing the strain at the peak in the stress-strain curves for the jute fiber reinforced concrete in compression, rather than increasing the compressive strength. The stress strain curves of the cube concrete specimens with different fiber volume and fiber length are presented in the Fig.4.3 and 4.4. The raw data for the load deformation values and strain with stress values of compressive test is presented in Annex C (Table A.4 and A.5) and (Table A.6 and A.7) respectively.

Table4. 6. 14 Day Strain at peak stress results of mix series II

Mix series II Specimen	Maximum compressive stress, f'c (MPa)	Strain at peak stress, e_o
Control	17.01	0.0085
$V_{0.5}L_5$	23.20	0.0119
$V_{0.5}L_{15}$	12.57	0.0068
$V_{0.5}L_{25}$	10.88	0.0051

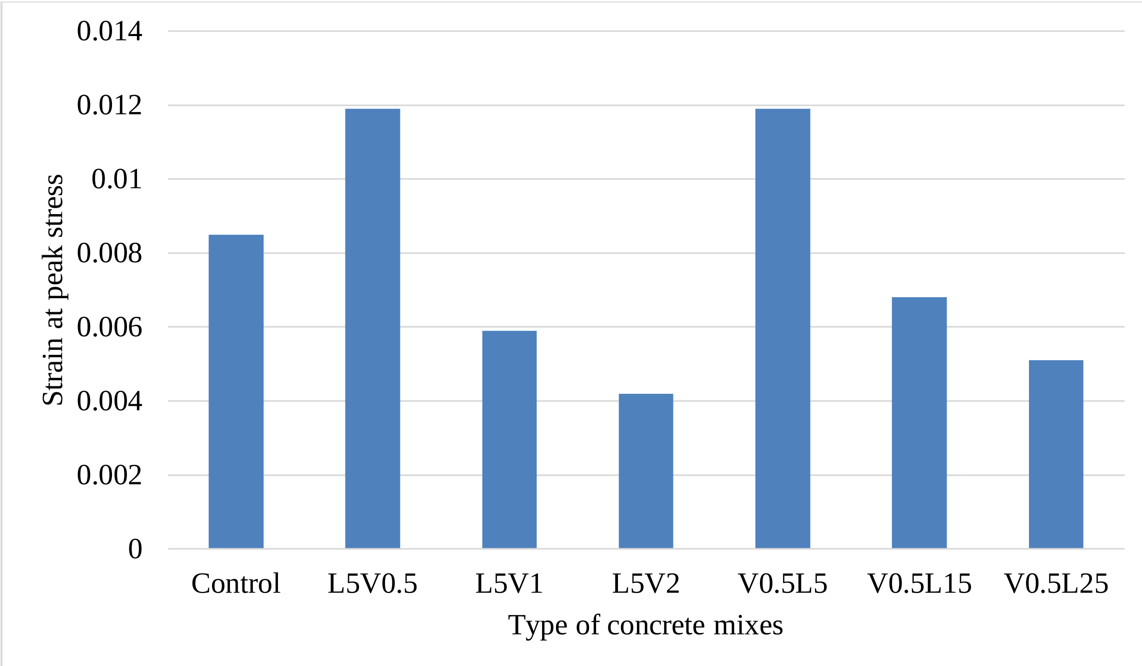

Fig 4. 5. Strain at peak stress graph of compressive test

The plain concrete specimens failure mode of compressive test is different from that of the jute fiber reinforced concrete that a sudden ejection of material was observed at the collapse, where as a more ductile collapse was seen for the jute fiber reinforced concrete specimen which the failure is not sudden and with increase in fibre-cement ratio, the cracks at failure load are observed to be very less. The jute fibre reinforced concrete has also morevisible crack as compared to control mix; this means that concrete mix with jute fiber reinforcement was more able to resist the crack propagation than its counterpart. This could be attributed to the fiber count and distribution within the specimens. This behavior of concrete specimens is in good agreement with the literature stated in section 2.8.4.

4.2.4. Split tensile strength test.

As explained in chapter 3, the 14 day split tensile strengths were determined. The table below shows the quantitative properties of the 14 day tensile strength as the mean of three specimens tested on the same day along with the standard deviation of the specimens and the relative strength gain or loss to that of the control mix. The raw data is presented in Annex D (Table A.10).

The 14^{th}days mean split tensile strength for the plain control mix for both the mix series is found to be 2.16 MPa. In the first mix, the fiber volume fraction ranging from 0.5% to 2% with 5mm length has resulted mean split tensile strength values varying from 1.99MPa to 2.33MPa with relative strength loss and gain of 7.87and 7.87 respectively. A decrease in split tensile strength was seen in the mixes L_5V_1 and $L_5V_2$with a relative compressive strength loss of 0.46 and 7.87respectively whereas the other remaining mix $L_5V_{0.5}$ shows an increase in the split tensile strength of 2.33MPa. The lowest strength value in this mix series was exhibited in mix L_5V_2, and the highest strength was seen in mix $L_5V_{0.5}$. Thus a direct relationship with an increase in fiber volume and split tensile strength test was not noticed in which increasing fiber content above 0.5% volume fraction starts to decrease the split tensile strength. (See Table 4.7 and Fig 4.6)

Table 4. 7. 14 day split tensile strength results of mix series I

Mix Design	Split tensile Strength (MPa)	Standard Deviation	Relative split tensile strength, σ gain or loss (%)
Control	**2.16**	0.14	N/A
$L_5V_{0.5}$	**2.33**	0.10	7.87
L_5V_1	**2.15**	0.17	-0.46
L_5V_2	**1.99**	0.09	-7.87

In the second mix, the mean split tensile strength of plain concrete is the same as the mix series above. Split tensile strength ranges from 1.8MPa to 2.33Mpa with a maximum relative strength loss and gain of 16.67 % and 7.87% respectively was obtained by inclusion of fibers of different length and 0.5% fiber loading. In this mix series a decrease in split tensile strength was observed in the mixes $V_{0.5}L_{15}$ and $V_{0.5}L_{25}$with a relative loss of 25% and 16.67%. In the remaining mix $V_{0.5}L_5$, an increase in split tensile strength was observed with a relative gain of 7.87%.The highest split tensile strength value was observed in mix $V_{0.5}L_5$.Further increment of length of jute fiber above 5mmdecreases the split tensile strength of the concrete. Thus direct relationship with an increase of fiber length and split tensile strength was not witnessed. (See Table 4.8 and Fig 4.6)

From the two mixes, it can be seen that the concrete mix with 0.5% fiber loading with 5mm length shows the best improvement of tensile strength. 7.87 % maximum increment is found.

Table 4. 8. 14 day split tensile strength results of mix series II

Mix Design	Split tensile Strength (MPa)	Standard Deviation	Relative split tensile strength, σ gain or loss (%)
Control	**2.16**	0.14	N/A
$V_{0.5}L_5$	**2.33**	0.10	7.87
$V_{0.5}L_{15}$	**1.62**	0.08	-25
$V_{0.5}L_{25}$	**1.80**	0.12	-16.67

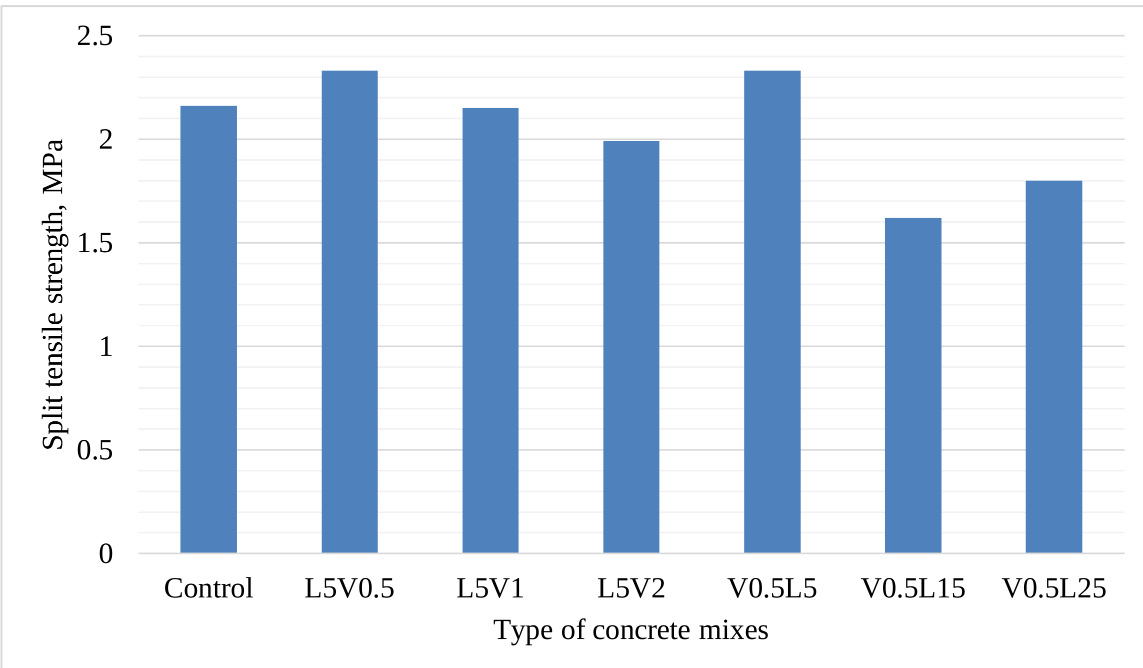

Fig 4. 6. 14 day split tensile strength of mix series I and II

The decrement of the tensile strength with higher content and length of jute fiber is because of the reason that the short fiber cut with lower content causes proper distribution of fiber and resist cracking the cylinder against the tensile load. More cracks are found when tensile failure of jute fiber reinforced concrete but the plain concrete exhibits the single and rapid crack, thus higher tensile strength is achieved with smaller volume content. Ultimate mode through further deflection without sudden collapse is observed for the jute fiber reinforced concrete. Thus the result is in harmony with the literature review in section 2.4.9.asthe studies of Rahul, T.Sai and B. Manoj and Mahommedet. al.

23% of tensile strength improvement has also been seen as a maximum value introducing jute yarn to the concrete was found by Mohammad et.al.which is far from the result obtained from this research but the improvement is achieved as this study. [11]

4.2.5. Flexural Strength

The flexural tensile strength tests of the fabricated concrete specimens were carried out using the two points loading which is also known as four point loading. It is a method used for testing the flexural tensile strength. This method is preferred over center point loading for the different advantages it possesses. In this test the concrete beam to be tested is supported at its ends and loaded at its interior location by gradually increasing load to failure. The failure load (loading value at which the concrete cracks heavily) is then recorded and used to determine the tensile at which the member failed, i.e. its tensile strength. The load deformation values are measured by the soil penetration gage attached during the test.

The mean flexural tensile strength of the two mix series are presented in Table 4.9 and 4.10 along with the standard deviation of the samples and the relative flexural strength loss and gain to that of the control mix. The raw data is presented in Annex E (Table A.11).

From the results shown above the flexural tensile strength of the control plain mix for both mix series I and II is found to be 6.53MPa. In the first mix, the flexural strength ranges from 2.58MPa to 10.08MPa with loss and gain of 60.49 % and 54.36% respectively with the inclusion of 5mm fibre length of different volume fraction. The highest flexural tensile strength was observed in the specimens with 0.5% volume fraction, $L_5V_{0.5}$inwhich a relative strength gain of 54.36 %is found. Thus from this result we can conclude that an increase in flexural tensile strength is observed with an increase of fibre volume up to 0.5%, but an increase of fibre volume above 0.5% decreases the strength gained. The results of this mix series is presented in Table 4.9.

In mix series II, the tensile strength values ranges from 4.02MPa to 10.08MPa with a relative strength loss and gain of 38.44% to 54.36% exhibited by the addition of 0.5% volume fraction of

Table 4. 9. 14 day flexural strength results of mix series I

Mix Design	Flexural strength, σ (MPa)	Standard Deviation	Relative strength σ Gain or loss (%)
Control	6.53	0.86	N/A
$L_5V_{0.5}$	10.08	0.77	54.36
L_5V_1	8.04	0.61	23.12
L_5V_2	2.58	0.17	-60.49

Table 4. 10. 14 day flexural strength results of mix series II

Mix Design	Flexural strength, σ (MPa)	Standard Deviation	Relative strength σ gain or loss (%)
Control	6.53	0.86	N/A
$V_{0.5}L_5$	10.08	0.77	54.36
$V_{0.5}L_{15}$	5.82	0.09	-10.87
$V_{0.5}L_{25}$	4.02	1.11	-38.44

fibres having different length to the concrete. The maximum flexural tensile strength from this mix series is registered in the mix $V_{0.5}$ L_5 gaining relative strength of 54.36% with flexural tensile strength 10.08MPa. $V_{0.5}L_{25}$mix exhibit the minimum flexural tensile strength with 4.02MPa gaining relatively strength loss of 38.44. Also in this mix series, further increment of fibre length above 5mm results in degradation of the strength having 0.5% fibre volume. Table 4.10 represents the flexural strength values of this mix series.

Generally from the two mix series, an addition of 0.5% volume fraction of fibre with 5mm length exhibited the highest flexural tensile strength. The flexural tensile strength test results presented in Table 4.9 and 4.10 is organized in graph form as shown in Fig. 4.7.

The specimen retains its integrity after occurrence of cracks with respect to control concrete and the decrement of the strength is caused by the balling of jute yarn which creates high porosity and weak zones in the specimen when the fibre loading and length is increased. The low cut lengths jute yarn detwist slowly and causes the even distribution of fibre and create the better reinforcement on composite. The load deformation graph for the bending test of the beam specimen is presented in the graph below in Fig. 4.8 and 4.9. The raw data of the load displacement values are presented in Annex E (Table A.12 and A.13).

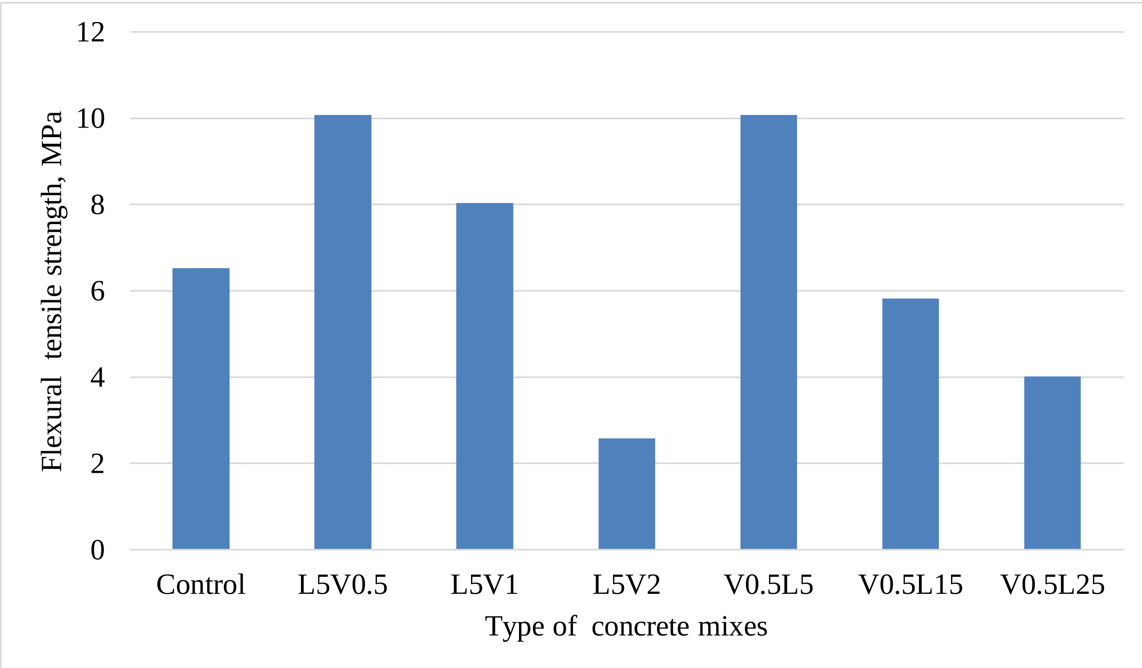

Fig 4. 7. 14 day flexural tensile strength of mix series I and II

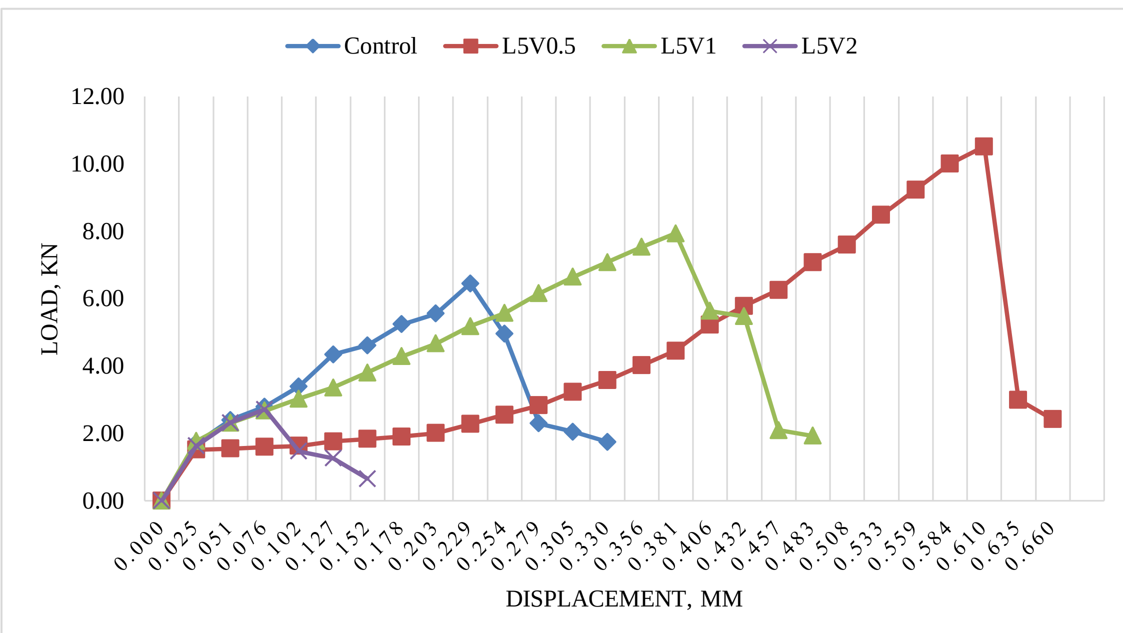

Fig 4. 8. Load displacement graph of bending test of mix series I

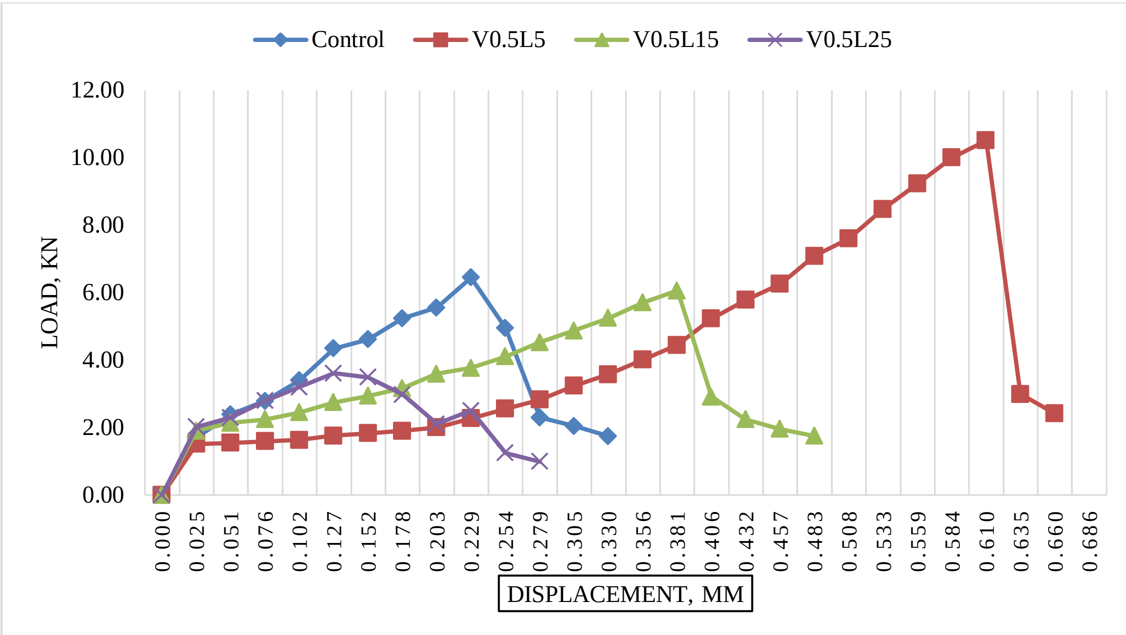

Fig 4. 9. Load displacement graph of bending test of mix series II

As shown in Fig. 4.8 and 4.9., the ascending branch does not change but significantly changes the descending branch of the load deformation curve in mix series I and II. Hence the ductility of concrete is significantly increased adding different volume fraction with different length of jute fiber in the concrete. But further increment of volume fraction and length more than 0.5% and 5mm length respectively decreases the ductility of the concrete. Thus adding jute fiber to concrete mix helps the concrete to sustain more deformation during loading. This improves that jute fiber addition can improve post peak behavior substantially. There is a significant change in the descending part of load-deformation curve since the fiber provides reinforcement which helps the concrete to be effective after considerable deformation have taken place in axial deformation. The peak load deformation values of bending test results are listed in Table 4.11 and 4.12.

Adding jute fiber with different volume fraction and different length to the concrete deformed more than two times than that of plain concrete.

Adding jute fiber to concrete also increased toughness. Toughness is defined as an ability of absorbing energy during loading. The toughness can be defined as the area under the load deformation curve. Tough higher amount of jute fiber increases ductility of concrete. The toughness of concrete is related to absorb energy in which the ductility is increased due to their energy absorption capacity. The jute fiber volume fraction and its aspect ratio played an important role in the toughness of the concrete which in turn affect the behavior of jute fiber reinforced concrete. The toughness was increased with the addition of jute fiber to the concrete mix. Thus the ductility was increased due to their energy absorption capacity.

Table 4. 11. Peak load deformation values of bending test results of mix series I

Mix series I Specimen	Maximum compressive load, Pmax (KN)	Deformation at peak load, µ
Control	6.44	0.229
$L_5V_{0.5}$	10.51	0.610
L_5V_1	7.94	0.381
L_5V_2	2.71	0.076

Table 4. 12. Peak load deformation values of bending test results of mix series II

Mix series I Specimen	Maximum compressive load, Pmax (KN)	Deformation at peak load, µ
Control	6.44	0.229
$V_{0.5}L_5$	10.51	0.610
$V_{0.5}L_{15}$	6.06	0.381
$V_{0.5}L_{25}$	3.61	0.127

The fiber did not increase the ultimate tensile strength appreciably but increase the tensile strains at rupture do. The matrix first-crack strength was not increased but the most significant enhancement is the post-cracking composite response.

Plain concrete failed suddenly once the deflection corresponding to the ultimate flexural strength is exceeded; on the other hand, fiber reinforced concrete continued to sustain considerable loads even at the deflection of the plain concrete.

Failure took place primarily due to fiber pullout or deboning in fiber reinforced concrete and unlike plain concrete a fiber reinforced concrete did not break immediately after the initiation of the first crack. This had the effect of increasing the work of fracture, which is referred to us toughness and represented by the area under the load deflection curve. In fiber reinforced concrete, crack density was increased, but the crack size was decreased.

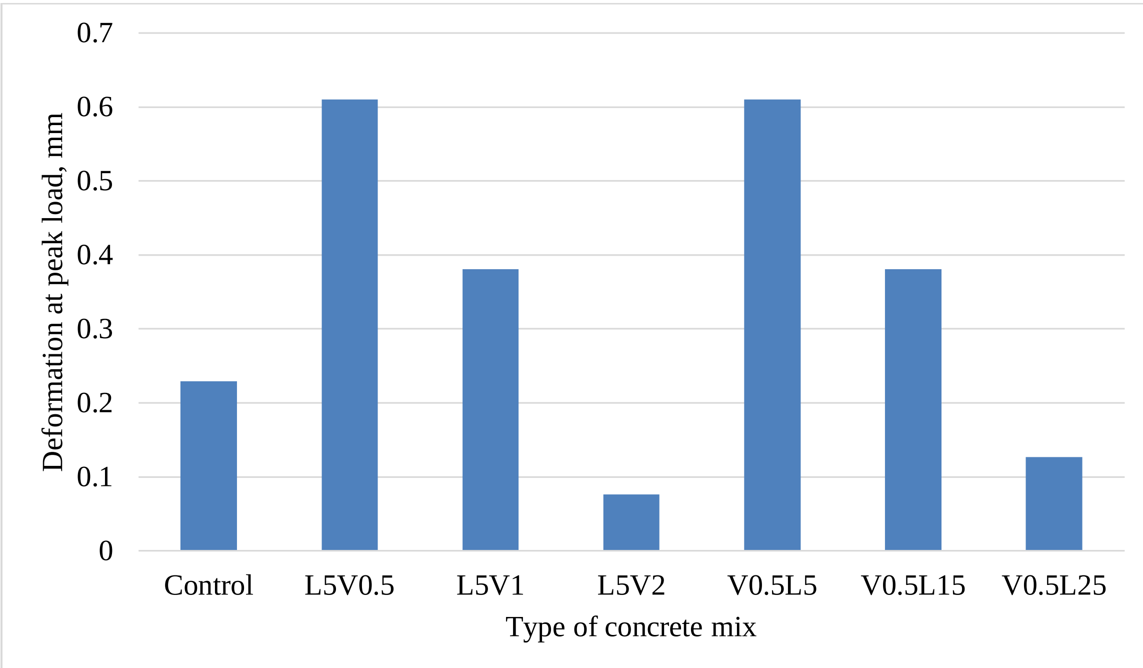

Fig 4. 10. Deformation of peak load graph of mix series I and II

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5. CONCLUSIONS

Based on the test of 36 specimens made with the available local materials, the following conclusions can be derived.

1. The addition of jute fibers strongly affected the workability of the fresh concrete that as the fiber loading and length increased, the workability is decreased.
2. A relative compressive strength loss and gain range of 4.57 to 33.14% was obtained by incorporating fibers of different volume to the concrete having 5mm length respectively. 34.29 % and 33.14% relative compressive strength loss and gain is exhibited by adding fibers of different length to the concrete having 0.5% fiber volume respectively. Thus, improvement of compressive strength is achieved by the presence of jute fibers in the concrete and the ultimate strength is significantly affected by the presence of jute fibers.
3. The strain corresponding to the peak stress for the fiber reinforced concrete is greater than that for the normal concrete. The strain increases with increasing fiber content and length but further increment above 0.5% fiber volume and 5mm length decreases the strain at peak stress respectively. Thus it improves the ductility behavior of the concrete.
4. A relative tensile strength loss and gain range of 7.87% to 7.87% respectively was obtained by introducing fibers of different volume to the concrete having 5mm length. And introducing 0.5% volume fraction of fiber with different length results in relative strength loss and gain range of 16.67% to 7.87% respectively. Thus it is possible to conclude it is likely to achieve considerable improvements in tensile strength by jute fiber inclusion and the ultimate strength is significantly affected by the presence of jute fibers.
5. Fiber inclusion of 0.5% volume fractions with different lengths resulted in substantial increase in flexural tensile strength loss and gain ranging 38.44% to 54.36%.And a relative flexural tensile strength loss and gain is obtained in range of 60.49% to

54.36% by adding different volume fraction of fibers with 5mm length. Therefore we can conclude that it is a promising result that adding fiber to the concrete mix will exhibit improvement in flexural strength and the ultimate flexural strength is strongly affected.

6. With the fiber inclusion of different lengths and volume fractions resulted in improvement of mechanical properties of the concrete matrix. Utilization of 0 to 0.5% volume fractions with 0 to 5mm length (0 to 2.15kg/m^3) is more efficient for ultimate failure strength gaining 33.14% relative compressive strength, 7.87% relative tensile strength and 54.36% relative flexural strength. But adding jute fiber with length above 5mm and volume fraction above 0.5% decreases the compressive, tensile and flexural strength of the concrete matrix.
7. Jute fiber reinforced concrete behaves as a homogeneous material and the random distribution and high surface-to-volume ratio (specific surface) of the fibers results in a better crack-arresting mechanism by improving the ductility of the concrete matrix and its post cracking load carrying capacity. With low fiber contents that are normally used in cement composites (from 0 to 2 % by volume of cement), the strain at which the matrix cracks is little different from that of plain concretes. Once cracking occurs, the fibers act as crack-arresters, and absorb a significant amount of energy as they are pulled out from the matrix without breaking.
8. Due to the low density of natural fibres used compared to artificial fibres the composites can be regarded as a useful light weight engineering material.
9. From the results obtained from this experimental study which is in good harmony with literature studies, jute fiber can be considered as promising and potential material in the construction industry here in our county using locally available materials.

6. RECOMMENDATIONS

Based on the investigation made the following recommendations are forwarded for studies in purpose of future excellence.

1. The promising results of this jute fiber as a reinforcing material in concrete necessitates that further research work is needed to have more knowledge about the material property and its applications.
2. Slump test is inadequate and satisfactorily to see the effects of fiber inclusion on the consistency of jute fiber reinforced concrete. Thus methods employing dynamic consolidation such as inverted slump cone test or vebe test should be used in order to get clearer view of effects of fiber inclusion.
3. The embrittlement of jute fiber reinforced building materials has been observed in some applications. The reason for such embrittlement has been found to be the alkaline pore-water in the composite which dissolves the fiber component. This can be counteracted by replacing 40 to 50% of the cement content by silica fume. The use of high alumina cement also reduces the alkalinity and thus slows down the rate of embrittlement. Sealing the pores with wax or resin, or use of suitable impregnating agents has also been observed to reduce embrittlement to a satisfactory level. So the chemical treatment of the jute fiber should be studied to prevent this embrittlement problem.
4. The performance properties like permeability, water absorption, thermal expansion, and shrinkage usually vary with fiber concentration. These can be significantly reduced by coating the surfaces with suitable paints or by using suitable admixtures. Thus test should be done to evaluate these properties.
5. The durability and performance of processed natural fiber reinforced cement is documented better than FRC made with unprocessed fibers. While the strength and elastic modulus of cement products reinforced with processed natural fibers (e.g., Kraft pulp) seem to actually increase up on weathering, more research is needed regarding the potential for embrittlement under exposure to some aggressive environments. The durability and moisture-sensitivity of unprocessed natural fibers are among the critical aspects of these composites that need to be further investigated. Research is needed to fully understand the mechanisms by which moisture and aggressive environments changes the failure mechanisms and thus affect the strength and toughness characteristics natural fiber reinforced composites. Potentials for the refinement of cementitious matrices in cellulose-cement composites to improve the durability characteristics also need further investigation. These refinements may be concerned with reducing the

alkalinity and permeability of the matrix.(ACI committee)For conclusion and recommendation from above literature review for conclusion

- Unprocessed natural fiber reinforced concrete is more vulnerable than other fiber reinforced concrete in terms of durability. The highly alkaline pore-water in the concrete seems to deteriorate the fibers.
- Durability can be substantially improved by replacing 40 to 50 percent of the cement with silica fume, since the addition of silica fume reacts with lime and considerably reduce the alkalinity of the pore water.
- Improved durability can be achieved by coating the fiber with suitable chemical such as fomic and stearic acid

6. The hybridization of these natural fibers has provided considerable improvement of tensile strength when compared to individual reinforcement which is mainly due to transfer of loads and shearing of loads among the fibers. So further study could be made on hybridization of natural fibers.
7. Besides its ability to sustain load, JFRC is also required to be sufficiently durable. To ensure durability, care should be taken to select suitable constituent materials in appropriate proportions and good quality jute fibers of specified length and volume fraction for producing a homogeneous and fully compacted mass. Poor dimensional stability of jute fibers are due to moisture changes gives rise to durability problems and various protective treatments have been found to improve the situation.
8. Since balling is the major problem in decreasing the strength of the jute fiber reinforced concrete there is a need to have a better solution for spreading the jute fiber around the concrete matrix to have a uniform dispersion.

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ANNEX A

MATERIAL TESTING OF C-30 CONCRETE GRADE

Gradation (dry), Fineness Modulus, Specific gravity, Water Absorption and Unit Weight of Fine Aggregate

a. Sieve analysis (AASHTO T-27)

Table A. 1. Sieve analysis results for coarse aggregate

Sieve Size (mm)	% Passing
3/8"(10.0)	99
No. 4 (4.75)	97
No. 8 (2.36)	94
No. 16 (1.18)	84
No. 30 (0.6)	57
No. 50 (0.3)	17
No. 100 (0.15)	4
No. 200 (0.075)	1

b. Fineness modulus = 2.5

c. Specific gravity (AASHTO T-84)

   i. Bulk specific gravity (Saturated Surface-dry, SSD) =2.407

   ii. Bulk specific gravity =2.32

d. Water absorption (AASHTO T-84) = 3.734%

e. Unit weight (Loose) = 1219 kg/m3

Gradation (Dry), Specific gravity, Water Absorption and Unit Weight of Coarse Aggregate

1. Sieve analysis (AASHTO T-27)

Table A. 2. Sieve analysis results for fine aggreagate

Sieve Size (mm)	% Passing
11/2 (37.5)	100
1” (25.0)	85
¼” (19.0)	49
½” (12.5)	18
3/8” (9.5)	6
No. 4 (4.75)	0.5
No. 200 (0.075)	0.1

2. Specific gravity (AASHTO T-84)
   a)Bulk specific gravity (Saturated surface-dry, SSD = 2.787
   b)Bulk specific gravity =2.747
3. Water absorption (AASHTO T-84) = 1.44%
4. Unit weight (Loose) = 1470 kg/m^3

ANNEX B

MIX DESIGN DATA SHEET

C-30 Concrete Mix Design

1. Proportion (Batch) Kg/m^3 of concrete

   Water = 195 lit/m3

   Cement = 430 kg/m3

   Fine aggregate (sand) = 462 kg/m3

   Coarse aggregate = 1274 kg/m3

2. Unit weight of fresh concrete = 2578 kg/m3
3. Unit weight of Aggregate (Loose)

   Fine aggregate (sand) pass 3/8" =1219 kg/m3

   Coarse aggregate size 02 = 1470 kg/m3

ANNEX C

COMPRESSIVE STRENGTH TEST RESULTS

Table A. 3. 14 day compressive strength results of mix series I and II

Mix Design	Cube No.	Dimensions (cm)			Weight (gm)	Area (cm^2)	Volume (cm^3)	Unit Weight (gm/cm3)	Failure Load (KN)	Compressive Strength (Mpa)	Relative compressive strength, σ gain or loss (%)
		L	W	H							
Control	Cu_1	15	15	15	8175.00	225.00	3375.00	2.42	394.36	17.53	
	Cu_2	15	15	15	8180.00	225.00	3375.00	2.42	391.54	17.40	
	Cu_3	15	15	15	8250.00	225.00	3375.00	2.44	395.59	17.58	
	Mean				**8201.67**	**225.00**	**3375.00**	**2.43**	**393.83**	**17.50**	
$L_5V_{0.5}$	Cu_4	15	15	15	8030.00	225.00	3375.00	2.38	505.34	22.46	
	Cu_5	15	15	15	8075.00	225.00	3375.00	2.39	518.40	23.04	
	Cu_6	15	15	15	8040.00	225.00	3375.00	2.38	549.20	24.41	
	Mean				**8048.33**	**225.00**	**3375.00**	**2.38**	**524.31**	**23.30**	33.14
L_5V_1	Cu_7	15	15	15	7840.00	225.00	3375.00	2.32	376.00	16.71	
	Cu_8	15	15	15	8105.00	225.00	3375.00	2.40	465.00	20.67	
	Cu_9	15	15	15	7895.00	225.00	3375.00	2.34	414.50	18.42	
	Mean				**7946.67**	**225.00**	**3375.00**	**2.35**	**418.50**	**18.60**	6.29
L_5V_2	Cu_{10}	15	15	15	7780.00	225.00	3375.00	2.31	368.27	16.37	
	Cu_{11}	15	15	15	7880.00	225.00	3375.00	2.33	368.68	16.38	
	Cu_{12}	15	15	15	7830.00	225.00	3375.00	2.32	390.50	17.36	
	Mean				**7830.00**	**225.00**	**3375.00**	**2.32**	**375.82**	**16.70**	-4.57
$V_{0.5}L_5$	Cu_4	15	15	15	8030.00	225.00	3375.00	2.38	505.34	22.46	
	Cu_5	15	15	15	8075.00	225.00	3375.00	2.39	518.40	23.04	
	Cu_6	15	15	15	8040.00	225.00	3375.00	2.38	549.20	24.41	
	Mean				**8048.33**	**225.00**	**3375.00**	**2.38**	**524.31**	**23.30**	33.14
$V_{0.5}L_{15}$	Cu_{13}	15	15	15	7980.00	225.00	3375.00	2.36	321.50	14.29	
	Cu_{14}	15	15	15	8165.00	225.00	3375.00	2.42	277.90	12.35	
	Cu_{15}	15	15	15	8335.00	225.00	3375.00	2.47	273.00	12.13	
	Mean				**8160.00**	**225.00**	**3375.00**	**2.42**	**290.80**	**12.92**	26.17
$V_{0.5}L_{25}$	Cu_{16}	15	15	15	7925.00	225.00	3375.00	2.35	256.25	11.39	
	Cu_{17}	15	15	15	7955.00	225.00	3375.00	2.36	266.55	11.85	
	Cu_{18}	15	15	15	8085.00	225.00	3375.00	2.40	253.40	11.26	
	Mean				**7988.33**	**225.00**	**3375.00**	**2.37**	**258.73**	**11.50**	-34.29

Table A. 4. 14 day compressive strength test results of mix series I (Load vs deformation)

Deformation (mm)	Load (KN)															
	Control				$L_5V_{0.5}$				L_5V_1				L_5V_2			
	Cu1	Cu2	Cu3	Mean	Cu4	Cu5	Cu6	Mean	Cu7	Cu8	Cu9	Mean	Cu10	Cu11	Cu12	Mean
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.13	25.17	37.20	29.66	30.68	21.68	16.00	42.00	26.56	36.00	35.00	27.77	32.92	39.00	12.43	19.00	23.48
0.25	66.87	83.40	62.44	70.90	58.00	43.00	118.00	73.00	95.00	93.84	65.08	84.64	72.00	39.80	38.00	49.93
0.38	124.00	163.50	104.16	130.55	118.00	93.00	236.00	149.00	197.00	189.00	134.10	173.37	116.00	76.79	70.00	87.60
0.51	177.00	253.20	157.86	196.02	229.00	166.00	395.00	263.33	339.00	298.00	257.20	298.07	168.00	125.00	119.00	137.33
0.64	235.00	315.40	208.20	252.87	434.00	273.00	525.00	410.67	371.00	409.00	390.50	390.17	211.00	174.00	179.00	188.00
0.76	294.00	366.90	268.40	309.77	499.00	394.00	547.00	480.00	376.00	451.00	411.20	412.73	248.00	220.00	255.00	241.00
0.89	347.00	391.54	321.60	353.38	505.34	511.00	549.20	521.85	374.00	463.00	414.50	417.17	285.00	259.00	325.00	289.67
1.02	382.00	387.74	362.80	377.51	501.70	518.00	546.00	521.90	369.00	465.00	410.20	414.73	317.00	300.00	367.00	328.00
1.14	405.88	373.50	389.85	389.74	488.72	506.91	537.00	510.88	364.00	461.00	405.70	410.23	339.00	333.00	384.00	352.00
1.27	406.14	366.53	395.59	389.42	471.42	493.00	517.00	493.81	356.00	448.00	400.90	401.63	356.00	353.00	389.00	366.00
1.40	360.97	357.24	394.00	370.74	454.00	479.48	498.00	477.16	349.00	433.00	391.40	391.13	367.00	365.00	389.94	373.98
1.52	394.36	338.11	380.32	370.93	447.00	464.45	488.00	466.48	340.00	422.00	386.23	382.74	368.27	367.00	389.27	374.85
1.65	386.45	326.32	372.86	361.88	432.91	449.03	469.00	450.31	335.37	411.00	377.75	374.71	366.00	368.00	387.58	373.86
1.78	380.00	315.17	361.59	352.25	418.58	432.65	451.00	434.08	326.81	403.00	372.39	367.40	365.00	368.10	385.46	372.85
1.91	374.06	305.95	357.68	345.90	405.03	411.66	436.00	417.56	321.17	390.43	367.89	359.83	362.00	368.50	382.43	370.98
2.03	368.18	299.20	343.38	336.92	392.08	393.24	424.00	403.11	313.20	381.00	362.35	352.18	360.00	368.68	376.87	368.52
2.16	363.49	286.10	335.67	328.42	380.84	376.94	419.00	392.26	308.34	373.00	358.35	346.56	358.00	368.15	373.26	366.47
2.29	356.91	256.81	328.13	313.95	369.00	362.24	410.00	380.41	301.38	367.20	352.91	340.50	353.00	367.67	368.57	363.08
2.41	359.08	246.69	326.06	310.61	363.00	349.08	400.00	370.69	297.20	360.74	349.52	335.82	350.00	366.34	365.27	360.54
Load at rupture	394.36	391.54	395.59	**393.83**	505.34	518.00	549.20	**524.18**	376.00	465.00	414.50	**418.50**	368.27	368.68	390.50	**375.82**

Table A. 5. 14 day compressive strength test results of mix series II (Load vs deformation)

Deformation (mm)	Load (KN)											
	$V_{0.5}L_5$				$V_{0.5}L_{15}$				$V_{0.5}L_{25}$			
	Cu4	Cu5	Cu6	Mean	Cu13	Cu14	Cu15	Mean	Cu16	Cu17	Cu18	Mean
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.13	21.68	16.00	42.00	26.56	5.87	3.84	20.13	9.95	16.53	4.03	3.51	8.02
0.25	58.00	43.00	118.00	73.00	14.20	6.16	42.17	20.84	24.63	4.65	4.60	11.29
0.38	118.00	93.00	236.00	149.00	28.50	9.82	101.24	46.52	46.13	5.57	5.98	19.23
0.51	229.00	166.00	395.00	263.33	61.20	15.40	179.34	85.31	92.83	6.55	6.73	35.37
0.64	434.00	273.00	525.00	410.67	122.10	22.89	247.82	130.94	153.00	9.99	8.48	57.16
0.76	499.00	394.00	547.00	480.00	206.30	36.50	272.45	171.75	196.00	24.20	10.80	77.00
0.89	505.34	511.00	549.20	521.85	277.40	97.91	273.23	216.18	232.00	56.50	15.20	101.23
1.02	501.70	518.00	546.00	521.90	313.50	156.20	263.57	244.42	252.00	98.30	27.10	125.80
1.14	488.72	506.91	537.00	510.88	320.20	256.50	255.09	277.26	256.25	144.10	61.20	153.85
1.27	471.42	493.00	517.00	493.81	321.50	277.90	249.15	282.85	249.78	183.20	110.50	181.16
1.40	454.00	479.48	498.00	477.16	320.81	276.20	244.32	280.44	242.50	217.50	169.10	209.70
1.52	447.00	464.45	488.00	466.48	316.20	272.50	240.43	276.38	234.82	243.40	205.70	227.97
1.65	432.91	449.03	469.00	450.31	311.50	265.40	236.69	271.20	230.52	259.55	229.10	239.72
1.78	418.58	432.65	451.00	434.08	305.40	259.30	233.07	265.92	224.82	266.55	243.20	244.86
1.91	405.03	411.66	436.00	417.56	300.30	251.50	231.21	261.00	217.98	261.78	253.40	244.39
2.03	392.08	393.24	424.00	403.11	295.20	246.30	229.41	256.97	214.50	256.96	252.95	241.47
2.16	380.84	376.94	419.00	392.26	290.31	242.40	227.82	253.51	210.13	254.58	249.37	238.03
2.29	369.00	362.24	410.00	380.41	284.50	238.10	225.08	249.23	207.08	254.13	246.10	235.77
2.41	363.00	349.08	400.00	370.69	278.10	211.50	224.10	237.90	203.62	253.98	240.96	232.85
Load at rupture	505.34	518.00	549.20	**524.18**	321.50	277.90	273.23	**290.88**	256.25	266.55	253.40	**258.73**

Table A. 6.14th Day compressive test results of mix series I (Stress vs Strain)

Strain	Stress(MPa)															
	Control				L5V0.5				L5V1				L5V2			
	Cu1	Cu2	Cu3	Mean	Cu4	Cu5	Cu6	Mean	Cu7	Cu8	Cu9	Mean	Cu10	Cu11	Cu12	Mean
0.0000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.0008	1.12	1.65	1.32	1.36	0.96	0.71	1.87	1.18	1.60	1.56	1.23	1.46	1.73	0.55	0.84	1.04
0.0017	2.97	3.71	2.78	3.15	2.58	1.91	5.24	3.24	4.22	4.17	2.89	3.76	3.20	1.77	1.69	2.22
0.0025	5.51	7.27	4.63	5.80	5.24	4.13	10.49	6.62	8.76	8.40	5.96	7.71	5.16	3.41	3.11	3.89
0.0034	7.87	11.25	7.02	8.71	10.18	7.38	17.56	11.70	15.07	13.24	11.43	13.25	16.37	5.56	5.29	9.07
0.0042	10.44	14.02	17.58	14.01	19.29	12.13	23.33	18.25	16.49	18.18	17.36	17.34	16.27	16.39	17.33	16.66
0.0051	13.07	17.40	11.93	14.13	22.18	17.51	24.31	21.33	16.71	20.04	18.28	18.34	16.22	16.36	17.30	16.63
0.0059	15.42	17.40	14.29	15.71	22.46	22.71	24.41	23.19	16.62	20.58	18.42	18.54	16.09	16.34	17.23	16.55
0.0068	16.98	17.23	16.12	16.78	22.30	23.02	24.27	23.20	16.40	20.67	18.23	18.43	16.00	16.28	17.13	16.47
0.0076	17.11	16.60	17.33	17.01	21.72	22.53	23.87	22.71	16.18	20.49	18.03	18.23	15.91	16.20	17.00	16.37
0.0085	17.17	16.29	17.58	17.01	20.95	21.91	22.98	21.95	15.82	19.91	17.82	17.85	15.69	15.69	16.75	16.04
0.0093	17.48	15.88	17.51	16.95	20.18	21.31	22.13	21.21	15.51	19.24	17.40	17.38	15.56	15.42	16.59	15.85
0.0102	17.53	15.03	16.90	16.49	19.87	20.64	21.69	20.73	15.11	18.76	17.17	17.01	14.92	15.20	16.38	15.50
0.0110	17.18	14.50	16.57	16.08	19.24	19.96	20.84	20.01	14.91	18.27	16.79	16.65	13.52	14.99	16.23	14.91
0.0119	16.89	14.01	16.07	15.66	18.60	19.23	20.04	19.29	14.52	17.91	16.55	16.33	12.24	13.42	16.10	13.92
0.0127	16.62	13.60	15.90	15.37	18.00	18.30	19.38	18.56	14.27	17.35	16.35	15.99	12.29	13.20	15.97	13.82
0.0135	16.36	13.30	15.26	14.97	17.43	17.48	18.84	17.92	13.92	16.93	16.10	15.65	11.32	12.89	15.23	13.15
0.0144	16.16	12.72	14.92	14.60	16.93	16.75	18.62	17.43	13.70	16.58	15.93	15.40	10.26	12.75	15.20	12.74
0.0152	15.86	11.41	14.58	13.95	16.40	16.10	18.22	16.91	13.39	16.32	15.68	15.13	10.20	12.63	14.96	12.60
0.0161	15.96	10.96	14.49	13.80	16.13	15.51	17.78	16.48	13.21	16.03	15.53	14.93	10.00	12.12	14.90	12.34
Stress at rupture	17.53	17.40	17.58	17.50	22.46	23.02	24.41	23.30	16.71	20.67	18.42	18.60	16.37	16.39	17.33	16.70

Table A. 7.14th Day compressive test results of mix series II (Stress vs Strain)

Strain	Stress(MPa)											
	$V_{0.5}L_5$				$V_{0.5}L_{15}$				V0.5L25			
	Cu4	Cu5	Cu6	Mean	Cu13	Cu14	Cu15	Mean	Cu16	Cu17	Cu18	Mean
0.0000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.0008	0.96	0.71	1.87	1.18	0.26	0.17	0.89	0.44	0.73	0.18	0.16	0.36
0.0017	2.58	1.91	5.24	3.24	0.63	0.27	1.87	0.93	1.09	0.21	0.20	0.50
0.0025	5.24	4.13	10.49	6.62	1.27	0.44	4.50	2.07	2.05	0.25	0.27	0.85
0.0034	10.18	7.38	17.56	11.70	2.72	0.68	7.97	3.79	4.13	0.29	0.30	1.57
0.0042	19.29	12.13	23.33	18.25	5.43	1.02	11.01	5.82	6.80	0.44	0.38	2.54
0.0051	22.18	17.51	24.31	21.33	9.17	1.62	12.11	7.63	8.71	1.08	0.48	3.42
0.0059	22.46	22.71	24.41	23.19	12.33	4.35	12.14	9.61	10.31	2.51	0.68	4.50
0.0068	22.30	23.02	24.27	23.20	13.93	6.94	11.71	10.86	11.20	4.37	1.20	5.59
0.0076	21.72	22.53	23.87	22.71	14.23	11.40	11.34	12.32	11.39	6.40	2.72	6.84
0.0085	20.95	21.91	22.98	21.95	14.29	12.35	11.07	12.57	11.10	8.14	4.91	8.05
0.0093	20.18	21.31	22.13	21.21	14.26	12.28	10.86	12.46	10.78	9.67	7.52	9.32
0.0102	19.87	20.64	21.69	20.73	14.05	12.11	10.69	12.28	10.44	10.82	9.14	10.13
0.0110	19.24	19.96	20.84	20.01	13.84	11.80	10.52	12.05	10.25	11.54	10.18	10.65
0.0119	18.60	19.23	20.04	19.29	13.57	11.52	10.36	11.82	9.99	11.85	10.81	10.88
0.0127	18.00	18.30	19.38	18.56	13.35	11.18	10.28	11.60	9.69	11.63	11.26	10.86
0.0135	17.43	17.48	18.84	17.92	13.12	10.95	10.20	11.42	9.53	11.42	11.24	10.73
0.0144	16.93	16.75	18.62	17.43	12.90	10.77	10.13	11.27	9.34	11.31	11.08	10.58
0.0152	16.40	16.10	18.22	16.91	12.64	10.58	10.00	11.08	9.20	11.29	10.94	10.48
0.0161	16.13	15.51	17.78	16.48	12.36	9.40	9.96	10.57	9.05	11.29	10.71	10.35
Stress at rupture	22.46	23.02	24.41	23.30	14.29	12.35	12.14	12.93	11.39	11.85	11.26	11.50

Table A. 8. Strain at peak stress values of compressive test result of mix series I

Mix series I Specimen	Maximum compressive stress, f'c (Mpa)	Strain at peak stress, e_o
Control	17.01	0.0085
$L_5V_{0.5}$	23.20	0.0119
L_5V_1	18.54	0.0059
L_5V_2	16.66	0.0042

Table A. 9. Strain at peak stress values of compressive test of mix series II

Mix series II Specimen	Maximum compressive stress, f'c (Mpa)	Strain at peak stress, e_o
Control	17.01	0.0085
$V_{0.5}L_5$	23.20	0.0119
$V_{0.5}L_{15}$	12.57	0.0068
$V_{0.5}L_{25}$	10.88	0.0051

ANNEX D

SPLIT TENSILE STRENGTH TEST RESULTS

Table A. 10. 14 day split tensile strength results of mix series I and II

Mix Design	Cylinder No.	Dimensions (cm)		Weight (gm)	Area (cm^2)	Volume (cm^3)	Unit Weight (gm/cm3)	Failure Load (KN)	Split tensile Strength (Mpa)	Relative split tensile strength, σ gain or loss (%)
		D	L							
Control	Cy_1	15	30	1289	176.63	5298.75	0.24	157.07	2.24	
	Cy_2	15	30	1301	176.63	5298.75	0.25	159.94	2.24	
	Cy_3	15	30	1290	176.63	5298.75	0.24	142.16	1.99	
	Mean			**1293.33**	**176.63**	**5298.75**	**0.24**	**153.06**	**2.16**	
$L_5V_{0.5}$	Cy_4	15	30	1309	176.63	5298.75	0.25	160.32	2.24	
	Cy_5	15	30	1307	176.63	5298.75	0.25	174.24	2.44	
	Cy_6	15	30	1305	176.63	5298.75	0.25	165.10	2.31	
	Mean			**1307.00**	**176.63**	**5298.75**	**0.25**	**166.55**	**2.33**	7.87
L_5V_1	Cy_7	15	30	1279	176.63	5298.75	0.24	139.68	1.96	
	Cy_8	15	30	1281	176.63	5298.75	0.24	156.23	2.19	
	Cy_9	15	30	1278	176.63	5298.75	0.24	164.59	2.30	
	Mean			**1279.33**	**176.63**	**5298.75**	**0.24**	**153.50**	**2.15**	-0.46
L_5V_2	Cy_{10}	15	30	1254	176.63	5298.75	0.24	134.84	1.89	
	Cy_{11}	15	30	1253	176.63	5298.75	0.24	147.79	2.07	
	Cy_{12}	15	30	1247	176.63	5298.75	0.24	143.91	2.01	
	Mean			**1251.33**	**176.63**	**5298.75**	**0.24**	**142.18**	**1.99**	-7.87
$V_{0.5}L_5$	Cy_4	15	30	1309	176.63	5298.75	0.25	160.32	2.24	
	Cy_5	15	30	1307	176.63	5298.75	0.25	174.24	2.44	
	Cy_6	15	30	1305	176.63	5298.75	0.25	165.10	2.31	
	Mean			**1307.00**	**176.63**	**5298.75**	**0.25**	**166.55**	**2.33**	7.87
$V_{0.5}L_{15}$	Cy_{13}	15	30	1279	176.63	5298.75	0.24	118.09	1.65	
	Cy_{14}	15	30	1287	176.63	5298.75	0.24	119.84	1.68	
	Cy_{15}	15	30	1286	176.63	5298.75	0.24	109.22	1.53	
	Mean			**1284.00**	**176.63**	**5298.75**	**0.24**	**115.72**	**1.62**	-25
$V_{0.5}L_{25}$	Cy_{16}	15	30	1277	176.63	5298.75	0.24	137.98	1.93	
	Cy_{17}	15	30	1272	176.63	5298.75	0.24	126.08	1.77	
	Cy_{18}	15	30	1269	176.63	5298.75	0.24	121.13	1.69	
	Mean			**1272.67**	**176.63**	**5298.75**	**0.24**	**128.40**	**1.80**	-16.67

ANNEX E

FLEXURAL TENSILE STRENGTH TEST RESULTS

Table A. 11. 14 day flexural tensile strength results of mix series I and II

Mix Design	Beam No.	Dimensions (cm)			P (KN)	M (KN.M)	I (cm^4)	C (mm)	σ (Mpa)	Relative flexural tensile strength, σ gain or loss (%)
		L	W	H						
L_5V_0	B_1	50	10	10	7.44	1.19	8.33	50.00	7.14	
	B_2	50	10	10	6.18	0.98	8.33	50.00	5.93	
	Mean				**6.81**	**1.09**	**8.33**	**50.00**	**6.53**	
$L_5V_{0.5}$	B_3	50	10	10	11.08	1.77	8.33	50.00	10.62	
	B_4	50	10	10	9.93	1.59	8.33	50.00	9.53	
	Mean				**10.51**	**1.68**	**8.33**	**50.00**	**10.08**	54.36
L_5V_1	B_5	50	10	10	7.93	1.27	8.33	50.00	7.61	
	B_6	50	10	10	8.82	1.41	8.33	50.00	8.47	
	Mean				**8.38**	**1.34**	**8.33**	**50.00**	**8.04**	23.12
L_5V_2	B_7	50	10	10	2.57	0.41	8.33	50.00	2.46	
	B_8	50	10	10	2.84	0.45	8.33	50.00	2.70	
	Mean				**2.71**	**0.43**	**8.33**	**50.00**	**2.58**	-60.49
$V_{0.5}L_5$	B_3	50	10	10	11.08	1.77	8.33	50.00	10.62	
	B_4	50	10	10	9.93	1.59	8.33	50.00	9.53	
	Mean				**10.51**	**1.68**	**8.33**	**50.00**	**10.08**	54.36
$V_{0.5}L_{15}$	B_9	50	10	10	5.99	0.96	8.33	50.00	5.75	
	B_{10}	50	10	10	6.12	0.98	8.33	50.00	5.88	
	Mean				**6.06**	**0.97**	**8.33**	**50.00**	**5.82**	-10.87
$V_{0.5}L_{25}$	B_{11}	50	10	10	3.37	0.54	8.33	50.00	3.23	
	B_{12}	50	10	10	5.00	0.80	8.33	50.00	4.80	
	Mean				**4.19**	**0.67**	**8.33**	**50.00**	**4.02**	-38.44

Table A. 12. 14 day bending test results for mix series I (Load vs deformation)

Deformation (mm)	Load (KN)											
	Control			$L_5V_{0.5}$			L_5V_1			L_5V2		
	B_1	B_2	Mean	B_3	B_4	Mean	B_5	B_6	Mean	B_7	B_8	Mean
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.03	1.63	1.77	1.70	1.51	1.51	1.51	1.72	1.81	1.77	1.62	1.62	1.62
0.05	2.42	2.36	2.39	1.55	1.54	1.55	2.40	2.20	2.30	2.31	2.31	2.31
0.08	2.83	2.74	2.79	1.58	1.60	1.59	2.70	2.63	2.67	2.57	2.84	2.71
0.10	3.42	3.36	3.39	1.54	1.71	1.63	3.03	3.01	3.02	1.43	1.50	1.47
0.13	4.56	4.12	4.34	1.63	1.88	1.76	3.34	3.37	3.36	1.21	1.30	1.26
0.15	4.78	4.44	4.61	1.71	1.94	1.83	3.80	3.79	3.80		1.29	0.65
0.18	5.29	5.18	5.24	1.78	2.02	1.90	4.27	4.29	4.28			
0.20	5.60	5.50	5.55	1.84	2.16	2.00	4.60	4.73	4.67			
0.23	6.70	6.18	6.44	2.14	2.40	2.27	5.13	5.23	5.18			
0.25	7.44	2.45	4.95	2.44	2.66	2.55	5.45	5.68	5.57			
0.28	2.45	2.13	2.29	2.69	2.96	2.83	6.13	6.17	6.15			
0.30	2.11	1.97	2.04	3.16	3.30	3.23	6.70	6.58	6.64			
0.33	1.84	1.64	1.74	3.45	3.69	3.57	7.12	7.03	7.08			
0.36				3.99	4.03	4.01	7.53	7.52	7.53			
0.38				4.38	4.51	4.45	7.93	7.94	7.94			
0.41				4.97	5.48	5.23	2.43	8.82	5.63			
0.43				5.53	6.03	5.78	2.15	8.79	5.47			
0.46				5.94	6.56	6.25	1.70	2.47	2.09			
0.48				6.97	7.19	7.08	1.67	2.18	1.93			
0.51				7.45	7.74	7.60						
0.53				8.56	8.39	8.48						
0.56				9.47	8.99	9.23						
0.58				10.30	9.70	10.00						
0.61				11.09	9.93	10.51						
0.64				2.76	3.22	2.99						
0.66				2.22	2.60	2.41						
0.69					2.37							
Load at rupture	7.44	6.18	**6.81**	11.09	9.93	**10.51**	7.93	8.82	**8.38**	2.57	2.84	**2.71**

Table A. 13. 14 day bending test results for mix series II (Load vs deformation)

Deformation (mm)	Load (KN)								
	$V_{0.5}L_5$			$V_{0.5}L_{15}$			$V_{0.5}L_{25}$		
	B_3	B_4	Mean	B_{10}	B_{11}	Mean	B_{12}	B_{13}	Mean
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.03	1.51	1.51	1.51	1.89	1.90	1.90	2.15	1.88	2.02
0.05	1.55	1.54	1.55	2.12	2.15	2.14	2.30	2.29	2.30
0.08	1.58	1.60	1.59	2.23	2.25	2.24	2.78	2.80	2.79
0.10	1.54	1.71	1.63	2.46	2.42	2.44	3.22	3.17	3.20
0.13	1.63	1.88	1.76	2.75	2.74	2.75	3.37	3.84	3.61
0.15	1.71	1.94	1.83	2.92	2.94	2.93	2.66	4.32	3.49
0.18	1.78	2.02	1.90	3.18	3.15	3.17	1.40	4.55	2.98
0.20	1.84	2.16	2.00	3.54	3.64	3.59		4.21	2.11
0.23	2.14	2.40	2.27	3.79	3.74	3.77		5.00	2.50
0.25	2.44	2.66	2.55	4.11	4.09	4.10		2.48	1.24
0.28	2.69	2.96	2.83	4.51	4.54	4.53		1.97	0.99
0.30	3.16	3.30	3.23	4.91	4.83	4.87			
0.33	3.45	3.69	3.57	5.25	5.23	5.24			
0.36	3.99	4.03	4.01	5.66	5.74	5.70			
0.38	4.38	4.51	4.45	5.99	6.12	6.06			
0.41	4.97	5.48	5.23	3.37	2.45	2.91			
0.43	5.53	6.03	5.78	2.39	2.08	2.24			
0.46	5.94	6.56	6.25	1.96	1.94	1.95			
0.48	6.97	7.19	7.08	1.76	1.73	1.75			
0.51	7.45	7.74	7.60	1.63					
0.53	8.56	8.39	8.48	1.54					
0.56	9.47	8.99	9.23	1.51					
0.58	10.30	9.70	10.00						
0.61	11.09	9.93	10.51						
0.64	2.76	3.22	2.99						
0.66	2.22	2.60	2.41						
0.69		2.37							
Load at rupture	11.09	9.93	**10.51**	5.99	6.12	**6.06**	3.37	5.00	**4.19**

Table A. 14. 14 day bending test results for mix series I (Peak load vs deformation)

Mix series I Specimen	Maximum compressive load, Pmax (KN)	Deformation at peak load, µ
Control		
B1	7.44	0.25
B2	6.18	0.23
Average	**6.81**	**0.24**
$L_5V_{0.5}$		
B1	11.09	0.64
B2	9.93	0.61
Average	**10.51**	**0.63**
L_5V_1		
B1	7.93	0.38
B2	8.82	0.41
Average	**8.38**	**0.40**
L_5V_2		
B1	2.57	0.08
B2	2.84	0.08
Average	**2.71**	**0.08**

Table A. 15. 14 day bending test results for mix series II (Peak load vs deformation)

Mix series II Specimen	Maximum compressive load, Pmax (KN)	Deformation at peak load, µ
Control		
Cu1	7.44	0.25
Cu2	6.18	0.23
Average	**6.81**	**0.24**
$V_{0.5}L_5$		
Cu4	11.09	0.64
Cu5	9.93	0.61
Average	**10.51**	**0.63**
$V_{0.5}L_{15}$		
Cu13	5.99	0.38
Cu14	6.12	0.38
Average	**6.06**	**0.38**
$V_{0.5}L_{25}$		
Cu16	3.37	0.13
Cu17	5.00	0.23
Average	**4.19**	**0.18**

ANNEX F

PHOTOGRAPHIC PRESENTATION

Fig A. 1. Raw jute fiber to be cut

Fig A. 2. Jute fibers ready for the mix

Fig A. 3. Chopped jute fiber

Fig A. 4 Compressive and tensile testing machine

Fig A. 5. Dry mixing

Fig A. 6. Lubricating beam mold

Fig A. 7. Lubricating the cube and cylinder molds

Fig A. 8. JFRC ready to be casted

Fig A. 9.JFRC ready to be casted

Fig A. 10. Distribution of fibers in JFRC

Fig A. 11. Preparing the slump

Fig A. 12. Slump for JFRC

Fig A. 13. Casting beam samples

Fig A. 14. Casting cube and cylinder samples

Fig A. 15. Trimming the samples

Fig A. 16. Casted samples after trimming

Fig A. 17. Samples ready to be cured

Fig A. 18. The curing tank

Fig A. 19. Curing the samples

Fig A. 20. Curing the samples

Fig A. 21. Crushing a cube sample

Fig A. 22. Crushing a cube sample

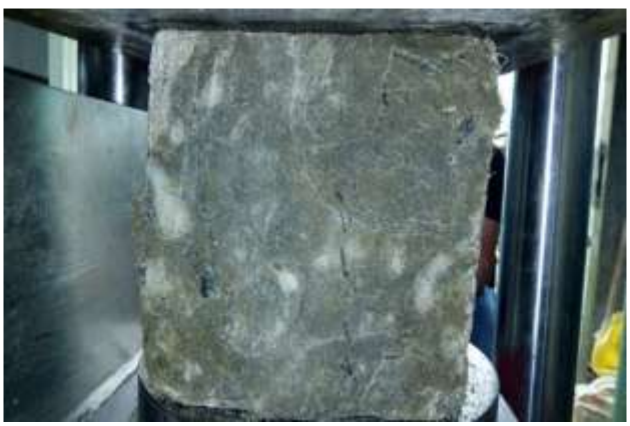

Fig A. 23. Failure mode of a cube sample

Fig A. 24. Compressive test with penetration gauge

Fig A. 25. Cubes prepared for weighing

Fig A. 26. Split tensile test with penetration gauge

Fig A. 27. Two point loading flexural test

Fig A. 28. Beam failure in flexure

Fig A. 29. Failure mode of cylinder sample

Fig A. 30. Weighing the materials for the mix

Fig A. 31. Spreading the jute fiber in the mix

Fig A. 32. Spreading the jute fiber in the mix

Fig A. 33. Tamping for slump test

Fig A. 34. Measuring slump of JFRC

Fig A. 35. Measuring slump of JFRC

Fig A. 36. Measuring slump of JFRC

Fig A. 37. Tamping the mix as vibration

Fig A. 38. Weighing the jute fiber sample

Fig A. 39. Dry mix of JFRC

Fig A. 40. Distribution of fibers in the concrete mix